Coal Combustion Products Extension Program

Final Report

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ABSTRACT

This final project report presents the activities and accomplishments of the Coal Combustion Products Extension Program conducted at The Ohio State University from August 1, 2000 to June 30, 2005 to advance the beneficial uses of coal combustion products (CCPs) in highway and construction, mine reclamation, agricultural, and manufacturing sectors. The objective of this technology transfer/research program at The Ohio State University was to promote the increased use of Ohio CCPs (fly ash, FGD material, bottom ash, and boiler slag) in applications that are technically sound, environmentally benign, and commercially competitive.

The project objective was accomplished by housing the CCP Extension Program within The Ohio State University College of Engineering with support from the university Extension Service and The Ohio State University Research Foundation. Dr. Tarunjit S. Butalia, an internationally reputed CCP expert and registered professional engineer, was the program coordinator. The program coordinator acted as liaison among CCP stakeholders in the state, produced information sheets, provided expertise in the field to those who desired it, sponsored and co-sponsored seminars, meetings, and speaking at these events, and generally worked to promote knowledge about the productive and proper application of CCPs as useful raw materials.

The major accomplishments of the program were:
- Increase in FGD material utilization rate from 8% in 1997 to more than 20% in 2005, and an increase in overall CCP utilization rate of 21% in 1997 to just under 30% in 2005 for the State of Ohio.
- Recognition as a “voice of trust” among Ohio and national CCP stakeholders (particularly regulatory agencies).
- Establishment of a national and international reputation, especially for the use of FGD materials and fly ash in construction applications.

It is recommended that to increase Ohio’s CCP utilization rate from 30% in 2005 to 40% by 2010, the CCP Extension Program be expanded at OSU, with support from state and federal agencies, utilities, trade groups, and the university, to focus on the following four specific areas of promise:
- Expanding use in proven areas (such as use of fly ash in concrete).
- Removing or reducing regulatory and perceptual barriers to use (by working in collaboration with regulatory agencies).
- Developing new or under-used large-volume market applications (such as structural fills).
- Placing greater emphasis on FGD byproducts utilization.
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EXECUTIVE SUMMARY

This project report presents the activities and accomplishments of the Coal Combustion Products Extension Program, a technology transfer / research program (DE-FC26-00NT40909), conducted at The Ohio State University from August 1, 2000 to June 30, 2005.

The objective of this program was to promote the use of Ohio coal generated CCPs (fly ash, bottom ash, boiler slag, and FGD material) in beneficial use applications that are technically sound, environmentally benign, and commercially competitive. The project objective was accomplished by housing the CCP Extension Program within The Ohio State University College of Engineering with support from the university Extension Service and The Ohio State University Research Foundation. Dr. Tarunjit S. Butalia, an internationally reputed CCP expert and registered professional engineer, was the program coordinator. The program coordinator acted as liaison among CCP stakeholders in the state, produced information sheets, provided expertise in the field to those who desired it, sponsored and co-sponsored seminars, meetings, and speaking at these events, and generally worked to promote knowledge about the productive and proper application of CCPs as useful raw materials.

The work carried out under this program involved developing, assessing, and technology transfer of promising CCP use technologies for commercial and end-use sectors.

The program is an active member of USEPA’s Coal Combustion Products Partnership (C2P2), American Coal Ash Association (ACAA), and Midwest Coal Ash Association (MCAA) and is recognized by the CCP industry as a leader promoting the use of CCPs in highway and construction, mine reclamation, agricultural, and manufacturing market segments.

The program accomplishments include:
- The target goal of 20% FGD material utilization for the state of Ohio by the end of 2005 has been exceeded. The overall CCP utilization of 30% by 2005 has been nearly achieved.
- The program is recognized by Ohio and national stakeholders (regulatory agencies, end-users, utilities, ash marketers, trade organizations, other research universities and centers) as a “voice of trust”.
- The program has established a national and international reputation especially for the beneficial use of fly ash and FGD materials in transportation and other construction market segments.

Increase in utilization rates of CCPs for the future will be particularly challenging because future regulatory requirements are likely to significantly increase the amount and possibly the types of by-products generated. This adds pressure to CCP use markets but will also present new technical challenges. In particular CCPs of the future are expected to have higher loadings of carbon (including unused activated carbon from mercury control) and may have higher concentrations of mercury and other adsorbed trace elements of concern for human health and the environment.

The CCP Extension Program should be continued at The Ohio State University with increased participation and support from the private sector, especially from the CCP industry (Ohio...
utilities, marketers, trade associations, and other stakeholders). The primary objective of the CCP Extension Program, the development, assessment, and technology transfer of promising CCP use technologies for commercial and end-use sectors, should focus on increasing the utilization rate of CCPs in Ohio from the current rate of 30% to 40% or more by 2010.

In order to achieve 40% utilization rate of CCPs by 2010 in the state, the following strategy should be implemented. The program should aid the CCP industry through education, technology transfer, and outreach in its efforts to:

- Expand use in proven areas
- Remove or reduce regulatory and perceptual barriers to use
- Develop new or under-used large-volume market applications, and
- Place greater emphasis on FGD byproducts utilization.

The focus of the program must remain on the high-volume uses of CCPs in construction, reclamation, and civil engineering applications. High-value manufacturing uses should receive particular attention. Although the agricultural uses of CCPs have been generally low-volume and value applications for generators, the demand for these uses has gained momentum in the agricultural community. Support for existing agricultural uses should be continued and promising future agricultural uses, such as the use of FGD gypsum as a soil amendment, should be advanced.

The recommendations for future work listed above will promote the use of high-sulfur Ohio coal by providing a positive revenue stream for the large quantities of CCPs (especially flue gas desulfurization material) generated from the combustion of coal and currently landfilled in the state. The end users of CCP beneficial utilization can expect cost savings as compared to the use of conventional natural resources. In particular, the increased use of fly ash to replace cement will significantly reduce CO₂ emissions associated with the use of cement (one ton of fly ash replacing cement will reduce about one ton of CO₂ emissions).
1 INTRODUCTION

1.1 Background and Objectives

Air pollution control regulations and rules for coal-fired power plants have resulted in cleaner air but have significantly increased the quantity of solid by-products generated. These by-products (commonly referred to as Coal Combustion Products (CCPs)) can be beneficially utilized or disposed in expensive landfills / impoundments. The recycling of these solid by-products into useable commodities is an important need arising from the increased installation of air pollution control devices at power plants. The beneficial use of CCPs in highway, construction, mine reclamation, agriculture, and manufacturing industry sectors provides for a strong and sustainable infrastructure, and promotes economic development in the state of Ohio.

The Coal Combustion Products (CCP) Extension Program at The Ohio State University (OSU) has been working since 1998, with co-funding from USDOE and OCDO, to promote the responsible uses of CCPs among stakeholders in Ohio through technology transfer and educational efforts. The program provides unbiased technical information to end users and regulators and is considered to be a “voice of trust.”

In the last seven years, the current program has worked with utilities and other stakeholders to significantly increase the utilization of CCPs (fly ash, bottom ash, boiler slag, and flue gas desulfurization material) in Ohio. In 1997, approximately 21% of CCPs generated in the state were utilized while only 8% of FGD materials generated were beneficially used. The goal of the
current CCP Extension Program was to work with Ohio CCP stakeholders to increase the overall CCP utilization rate to about 30% by the year 2005, and FGD utilization rate to about 20% by 2005.

1.2 Outline of Report

Chapter 1 presents an introduction to the report. The development and implementation of the CCP Extension Program is outlined in Chapter 2. It includes a discussion on the activities carried out under the program, a 2005 review of the Ohio CCP Marketing Report prepared by the co-authors in 2000, and highlights the major accomplishments of the program. Summary, conclusions, and recommendations for future work are presented in Chapter 3. Several appendices at the end of the report provide additional documentation for this technology transfer effort.
2 EXPERIMENTAL / PROGRAM IMPLEMENTATION

2.1 Introduction

The CCP Pilot Extension Program was established at OSU in January of 1998 under the principal sponsorship of The Ohio Coal Development Office (OCDO) and The Ohio State University (OSU). Co-sponsors included Federal Energy Technology Center of USDOE, American Electric Power, Cinergy, FirstEnergy, Dravo Lime Company, American Coal Ash Association (ACAA) - National and Ohio Chapter, Ohio Farm Bureau Federation, Ohio Dairy Farmers Association, and Ohio Cattlemen’s Association. A qualified CCP expert, Dr. Tarunjit Singh Butalia, was interviewed and selected to serve as the statewide CCP pilot coordinator at OSU.

Based on the success of the pilot program, the full-fledged CCP Extension Program (detailed in this report) was established in October of 2000. The program was housed within The Ohio State University’s College of Engineering with support from the university Extension Service and The Ohio State University Research Foundation. The program coordinator, Dr. Tarunjit S. Butalia, an internationally reputed CCP expert and registered professional engineer, was retained to lead the program. The program coordinator acted as a liaison among CCP stakeholders in the state, produced information sheets, provided expertise in the field to those who desired it, sponsored and co-sponsored seminars, meetings, and speaking at these events, and generally worked to promote knowledge about the productive and proper application of CCPs as useful raw materials.
The beneficial use of CCPs as productive raw materials in place of non-productive landfill / impoundment disposal results in several direct, indirect and societal benefits for CCP producers, end-users, the environment, and ratepayers. The benefits associated with CCP utilization are:

- emphasis on recycling and decrease in the need for landfill space,
- conservation of natural resources of the state,
- better products and significant technical benefits,
- reduction in the cost of energy production for utilities,
- substantial cost savings for end-users,
- continued economic competitiveness of high-sulfur Ohio coal,
- cleaner and safer environment,
- reduced social costs, and
- greater economic development.

These technical, environmental, social, and economic issues need to be in balance for the effective use of a CCP for a particular application. Successful CCP uses are those that are technically safe, environmentally sound, socially beneficial, and commercially competitive, as with any other raw material or product of commerce.
2.2 2005 Review of the 2000 Ohio CCP Marketing Report

An extensive and detailed CCP marketing study for Ohio was compiled by the co-authors of this report as a part of the previous CCP Pilot Extension Program and was published in May 2000. The complete report (Volume 1 – Executive Summary, and Volume 2: Findings, Recommendations, and Conclusions) and its Executive Summary titled Market Opportunities for Utilization of Ohio Flue Gas Desulfurization (FGD) and Other Coal Combustion Products (CCPs) by T.S. Butalia and W.E. Wolfe can be accessed at http://ccpohio.eng.ohio-state.edu. The report presented 1997 CCP production and utilization data for coal-fired facilities in Ohio and evaluated the potential uses of CCPs for various market segments.

CCPs generated in the state are of four types: fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) material. In 1997, Ohio generated approximately 9.2 million tons of Coal Combustion Products (CCPs) and utilized about 20% of them in various application technologies. The remaining 80% were typically disposed in landfills or surface impoundments. Ohio generated a significant amount of stabilized FGD material (3.8 million tons on wet basis, and 2.68 million tons on dry basis) annually to comply with the Clean Air Act Amendments of 1990, which restrict SO₂ emissions from many coal-fired facilities that use high-sulfur coal. The FGD utilization rate was a bleak 8.4% in 1997.

Recent CCP surveys indicate that in 2003 approximately 10 million tons of CCPs were generated in the state of Ohio. In 2003, the CCP utilization rate was 27%, while the FGD utilization rate exceeded 25%. Hence it can be observed that the current CCP Extension
Program’s target of 30% utilization of CCPs by 2005 will be met by the end of the year 2005, and the target of 20% utilization of FGD material by 2005 has already been achieved. For 2003, the Ohio CCP utilization market segments are shown below in Figure 2.1. It can be observed that the leading market segment for CCP use is the use of fly ash in concrete and the use of FGD materials in wallboard manufacture, both combined accounting for over 55% of CCP use in the state. Use of fly ash and bottom ash in structural fills and highway embankments account for slightly more than 15% of use, while use of boiler slag in blasting grit and roofing granule applications accounts for less than 10% of CCP use in the state. Mining applications account for less than 7% of CCP beneficial use. Other such as use of bottom ash for snow and ice control, fly ash and bottom ash for road base and subgrade stabilization, and fly ash in flowable fills account for less than 8% of use. Agricultural and mineral filler uses of CCPs are much lower than 1%.

![Figure 2.1 Ohio CCP Market Segments for 2003](image-url)
Many of the CCP uses listed above, if treated and applied properly, can be low-cost substitutes for conventional raw materials in highway and related civil engineering applications, reclamation uses, manufacturing industry, and agricultural applications. Potential high volume uses for FGD materials exist in highway and related civil engineering applications throughout the state, reclamation in the eastern third of the state, and wallboard manufacture. High value markets exist for CCP uses in the manufacturing industry. Agricultural uses generally will be low volume and low value uses for the CCP provider. However, they are attractive low cost alternatives that are generating increased interest and demand by the agricultural community. Significant environmental benefits from mine reclamation work can result due to reduction in acid mine drainage and sedimentation problems. The key to the success of CCP utilization in Ohio has been to maintain and expand the volume of current CCP use application technologies and the development of high-volume, high-value new innovative uses for FGD material and fly ash. The potential large volume utilization of CCPs as raw material substitutes for conventional materials have significant technical benefits, economic advantages for utilities and end users, and environmental as well as social benefits. However, several drawbacks, limitations, and barriers to CCP utilization still exist in the state. The barriers to CCP use in Ohio are regulatory (federal and state), legal, and institutional (economics, marketing, environmental and perception related, and technical). The 2000 Ohio CCP marketing report included ten recommendations for the removal / reduction of barriers to CCP utilization. These barriers can be overcome with the synergy and focused attention of government agencies, utility industry, trade organizations, and university research and technology transfer and market development programs. The removal of these barriers and a strong CCP extension / market development program are critical to the future high
volume uses of CCPs, particularly for FGD material and fly ash in the state of Ohio. The long-term successful utilization of CCPs that are technically safe, environmentally sound, socially beneficial, and commercially competitive will allow Ohio coal to remain competitive with other coal sources, and keep the cost of energy production low while protecting human health and the environment.

The ten recommendations of the 2000 Ohio CCP Marketing Report and the response to each recommendation are listed below:

**Recommendation No. 1:** “Because FGD material and its leachate generally have lower concentration of trace elements of concern than fly ash, OEPA should consider regulating FGD material as an exempt waste in a fashion similar to non-toxic fly ash instead of the current regulation of FGD as a residual solid waste. Appropriate changes to Ohio Revised Code and Ohio Administrative Code may be necessary.”

*Response:* Technical information was compiled on the safety of the FGD material and provided to OEPA as a part of the Coal Combustion Residues Industry Group convened by OEPA. OEPA is now consulting with other by-product stream generators as it considers streamlining its waste disposal and beneficial use guidelines and regulations. Changes to Ohio Revised Code and Ohio Administrative Code will then follow.

**Recommendation No. 2:** “OEPA should expedite its current internal review of waste regulations. The agency should develop and implement a Long Term Alternative Waste Management
Program, in consultation with a CCP stakeholder external advisory group, which includes recognition of CCPs in established markets as produced co-products rather than wastes.”

_Response:_ The program assisted OEPA with forming an interim Coal Combustion Residues Industry Group. The concept of manufactured co-products for use of fly ash in concrete, synthetic aggregate etc. is recognized by the agency.

**Recommendation No. 3:** “ODOT should review its current specifications with regard to fly ash, bottom ash, boiler slag, and FGD, and incorporate the additional uses of CCPs into ODOT specifications.”

_Response:_ The program has repeatedly called upon ODOT to revise its specifications to be inclusive of CCPs. A specification drafted by ODOT for use of fly and bottom ash in highway embankments was reviewed and comments provided to ODOT. Many of the technical comments were accepted by ODOT.

**Recommendation No. 4:** “CCP generators should develop improved quality assurance / quality control testing methods and implement them at generating facilities so that the quality of CCPs generated is consistent.”

_Response:_ With the transition of the CCP industry from one managed by utilities to that of ash marketers, the issues relating to QA/QC have improved significantly. The program works closely with the various ash marketers across the state in identifying QA/QC issues that ODOT and other regulators ascertain need to be addressed.
**Recommendation No. 5:** “For long-term effective utilization of CCPs, transportation and processing costs should be borne by the end-user. For the short-term, CCP generators should continue to cover costs associated with FGD transport within a specified delivery area for high volume and/or high value projects or products, up to the break-even point on cost avoidance. Minimum delivery rates (i.e., schedule and volume) should be assured by generators, subject to electric generation, to potential large volume end-users.”

**Response:** Utilities have continued to cover the cost of FGD transport within limited distance from the plant. In general, ash marketers are now able to assure tonnage of CCP materials for large CCP use projects in the construction industry.

**Recommendation No. 6:** “Improved specifications, fact sheets, design manuals, and testing procedures need to be developed and widely distributed by the CCP industry and university researchers in collaboration with standard-setting organizations.”

**Response:** The program has worked closely with ASTM, ODOT, OEPA, ODNR-DMR, ACAA, and MCAA to develop improved standards for testing and use of these materials.

**Recommendation No. 7:** “Ohio research should continue to focus on promising uses of CCPs, particularly FGD and fly ash, with the co-funding from state and federal agencies, utilities, trade organizations, and research universities. Particular areas of research interest should be high-volume highway applications, high-value manufacturing uses, environmentally beneficial reclamation uses, durability issues, effects of new emission restrictions (e.g., NOx control), chemical forms of elements of concern in CCPs and their solubility and mobility in the environment, and long-term effects.”
Response: Similar research priorities have been adopted by CBRC, OCDO, ACAA, USDOE and other funders of CCP research.

Recommendation No. 8: “The CCP pilot extension program at The Ohio State University should work with the central and district offices of OEPA and ODOT, and county, municipal, and township engineering organizations, to provide technical information about CCP utilization. Further, the CCP pilot program should review as well as address the concerns of personnel at these agencies.”

Response: The CCP Extension Program has visited and met with personnel of all district and central offices of OEPA and ODOT. Meetings have been held with the Ohio County Engineer’s Office.

Recommendation No. 9: “Continuance of the CCP pilot extension program currently in place at The Ohio State University should be explored in collaboration with the university, state agencies, utilities, and trade organizations.”

Response: This CCP Extension Program was continued till 6/30/05 with funding from the university, OCDO, Ohio utilities and ash marketers, and trade organizations.

Recommendation No. 10: “Efforts to educate regulators, engineering consultants, potential end users, and the general public should continue. The educational efforts should focus on neutralizing the association of “waste” with CCPs, and should emphasize the environmental safety (non-toxicity) of CCPs, their potential uses, benefits and drawbacks. The public in
particular should be made aware of the environmental costs of landfilling, and the environmental
and social benefits resulting from reclamation and other efforts using CCPs.”

Response: Educational efforts have been the focus of the CCP Extension Program through
seminars, presentations, exhibit booths, posters, publicity articles, positive media reports, letters
to the editor of newspapers, and involvement in environmental organizations.

Increase in utilization rates of CCPs for the future is particularly challenging because future
regulatory requirements are likely to significantly increase the amount and possibly the types of
by-products generated. This adds pressure to CCP use markets but will also present new
technical challenges. In particular CCPs of the future are expected to have higher loadings of
carbon (including unused activated carbon from mercury control). USEPA announced on March
15, 2005 new rules that will reduce power-plant emissions of mercury by 70% by 2020. The
nation’s current annual mercury emissions from coal-fired power plants of 48 tons a year will be
reduced to 38 tons by 2010, and to 15 tons by 2018. Ohio currently ranks third in mercury
emissions with approximately 3.5 tons of mercury emitted in 2002. Mercury and additional air
pollution control regulations will increase the concentration of some trace elements in the solid
by-products. These higher concentrations of mercury and other adsorbed trace elements of
concern for human health and the environment will add additional pressure to the beneficial use
of CCPs. The CCP industry and stakeholders will need to re-double their efforts in increasing
utilization rates to 40% or more by 2010.
2.3 Summary of Program Activities

The major activities of the CCP Extension Program over the last five years can be summarized as:

1. Working with regulatory agencies such as OEPA, USEPA, ODOT, ODNR, FHWA, USDOI-OSM etc. to produce environmental and technical guidelines and standards for CCP use in highway and construction, mine reclamation, agricultural, and manufacturing sectors.
2. Working towards overcoming regulatory, technical, economic, marketing, and public perception barriers to use of CCPs.
3. Establishing a CCPOhio website at OSU (http://ccpohio.eng.ohio-state.edu) and maintaining it on a regular basis.
4. Preparing and regularly updating educational materials for end-users, such as four fact sheets (see Appendix E), which provide detailed instruction on various uses of CCPs.
5. Conducting workshops across the State of Ohio to train end-users and others in the advantages and proper application of CCPs.
6. Demonstrating the use of CCPs via preparation of informational materials, papers, presentations, press releases, web site, etc. See Appendix B for list of published book chapters, and journal and conference proceeding articles.
7. Maintaining an Ohio-specific CCP database in collaboration with ACAA, updating it regularly, and providing information to stakeholders.
8. Serving as a liaison among CCP stakeholders in the state. These include utilities, ash marketers, regulatory and government agencies, end-users, environmental groups, trade organizations, educators, and researchers.
9. Working with generators, manufacturers, and others to produce value added products from or with CCPs that will benefit the use of Ohio coal, and provide technical, environmental, economic, and other benefits to the state of Ohio.

The program focused on the highway / construction uses and related civil engineering applications. Mine reclamation and manufacturing uses also received significant attention. Existing agricultural uses, such FGD feedlots, were also advanced while promising future uses (such as soil amendment) were evaluated and supported.

In specific, the following activities were carried out as a part of the CCP extension Program:

- **Overcoming barriers to CCP use**
  - Convened with OEPA a Coal Combustion Residues industry group to review and potentially revise the regulations governing use of CCPs and other solid wasters regulated by OEPA. Encouraged OEPA to form an External Advisory Group for CCPs.
  - Developed mechanisms to overcome the three main barriers to CCP use in the state – regulatory, quality assurance / quality control of product, and economic considerations by working with ash marketers such as Headwater Resources and Fly Ash Direct.
  - Partnered with major CCP stakeholders to overcome barriers to use. This partnership involved OEPA, ODOT, OCDO, USDOE, CBRC, USEPA, FHWA, USDOI-OSM, Ohio coal-fired utilities (AEP, First Energy, Cinergy, Dayton Power and Light, etc.), ash marketers
(Headwater Resources, Fly Ash Direct), and trade groups (ACAA, MCAA, Ohio Farm Bureau Federation, Ohio Mineland Partnership, Ohio Rural Development Federation, etc.).

- Met with central and district office personnel of OEPA to review as well as address concerns relating to CCP characteristics, and regulations.
- Compiled technical information on the non-toxicity of FGD material and fly ash materials and worked with OEPA to promote the regulations of FGD material as a residual solid waste to exempt resource material (in a fashion similar to non-toxic fly ash). The agency has expressed a possible step in this direction when the current rules for various types of by-products are revised.
- Worked with end-users and ash marketers to provide information on economic issues relating to landfilling cost and transportation.
- Educated end-users, especially ODOT, which would potentially use federally funded dollars, about federal procurement guidelines on CCP uses. Copies of the federal procurement guidelines were submitted and discussed with ODOT.

- **Advancing highway-related uses**
  - Reviewed ODOT specifications for increased CCP use and worked with ODOT district and central office personnel to effect positive changes in specifications followed throughout the state. Provided review of proposed ODOT specification for use of fly ash and bottom ash in structural fills.
  - Provided technical assistance on the engineering characteristics and use of CCPs to ODOT district and county engineers. Reviewed and addressed concerns of these personnel.
• Provided technical information on characteristics, proper application, and advantages of CCP uses at Ohio-specific conferences such as the annual Ohio Transportation Engineering Conference (OTEC). Attended OTEC conferences in Columbus, displayed extension program booth, and presented a paper on the highway applications of CCPs.

• Met with highway officials in neighboring states such as Indiana, West Virginia, Kentucky, and Michigan to review their specifications and compared them with those in Ohio.

• Demonstrated the use of CCPs in structural and embankment fill, cement concrete, asphalt concrete, stabilized base / sub-base, manufactured aggregate, flowable fill, grout applications, and rural roads through conference and seminar presentations.

• Held a technology transfer seminar at OSU on April 22, 2005 attended by industry, state, academia, and concrete industry representatives. The speaker was Dr. Richard Kruger of South Africa.

• Exhibited a booth on the CCP Extension Program at the World of Coal Ash in Lexington, KY, April 14-17, 2005.

• Presented a paper on the use of fly ash in road applications at the C2P2 workshop in Puerto Rico, February 24, 2005, organized by UESPA and ACAA.

• Published the lead article in the Energeia magazine, Vol. 15, No. 4, 2004 (published by UK-CAER) titled “Corrosion in Concrete and The Role of Fly Ash in its Mitigation”. The ASCE’s new committee on pozzolans has invited Dr. Butalia to submit a revised form of this article for publication in the Civil Engineering magazine, the main monthly publication of ASCE.
• The program coordinator participated in an Ohio specific Environmental Concrete Alliance in 2001. The alliance was considering mechanisms by which to increase the use of fly ash in concrete.

• The 2000 quarterly newsletter of the Ohio Alliance for the Environment published an article “Fly Ash in Concrete: An Environmentally Desirable Product” by Dr. Tarunjit S. Butalia.

- Advancing mine reclamation uses

• Worked with ODNR-DMR’s abandoned mine land program to develop guidelines for use of CCPs for re-mining permit applications with a focus on hydrological issues.

• Served on the Coal Combustion By-Products National Steering Committee of the United States Department of Interior’s Office of Surface Mining since 1998. This national steering committee is charged with developing a coal combustion by-products information network that is accessible to potential users in the coal mining community. Steering committee members include representatives of federal and state agencies, and research universities. The CCP Extension Program is working with the committee to hold a CCB Forum in Columbus, Ohio, November 13-17, 2005.

• Educated ODNR-DMR and other regulatory personnel on uses of FGD material and fly ash in mine reclamation. A technical presentation titled “Coal Combustion By-Products: Opportunities for Reclamation Partnership” was made at National Association of Abandoned Mined Lands Annual Conference, Ohio University, Athens, August 19-21, 2001.

• Worked with ODOT and ODNR-DMR towards increased use of CCP-based grouts for subsidence control and Remediation. Reviewed the underground mapping report prepared by ODOT.
• Advanced the use of CCPs (particularly FGD material) at current mining operations by presentations at Ohio Mineland Partnership seminars. Issues relating to haulback and treatment of coal refuse were addressed.

• Advanced the increased use of FGD material in the reclamation of abandoned mined lands (especially gob piles and spoil areas) for acid mine drainage remediation and sedimentation control. Successful projects of this nature, such as Rock Run were documented and shared at conferences, seminars, and workshops.

 Advancing agricultural uses

• Updated and promoted OSU Extension Fact Sheets for FGD feeding and hay storage pads. Sent copies of the Fact Sheets to every County Extension Office.

• Worked with AEP in assisting in the installation of over 150 FGD pads in over 12 counties across the state.

• Promoted the advantages of using FGD material as an agricultural liming substitute.

• Provided technical information on and advance the use of FGD material based low-permeability liners for ponds, manure storage facilities, and wetlands.

• The Associated Press interviewed Dr. Butalia and published his comments as a part of its wire story published September 5, 2001 titled “Researchers say waste coal ash could improve feedlot condition.” Many major newspapers across the US published the wire report.

• Comments by the program coordinator were published as a part of a Waste News, September 17, 2001 article titled “Coal Byproduct might aid farmers: Researchers in ND and Ohio use ash from power plants to stabilize soils.”
• Met with personnel of Ohio Department of Agriculture and OhioEPA to promote the increased use of FGD gypsum for agricultural and horticultural applications.

☐ Other activities/services

• Organized several conference and seminars (see Appendix C).

• Member of ASTM E50.03, American Society for Testing and Materials Subcommittee on Environmental Assessment since 2000. The subcommittee is charged with developing national consensus standards for characterization and use of coal combustion by-products.

• Researched the potential use of FGD material in the construction of landfill caps.

• Provided technical assistance and information (including demonstration project results) to engineering design consultants such as GAI consultants.

• Participated in recycling workshops conducted by ODNR to reduce the perception of CCPs as wastes. Worked towards educating the public on the environmental safety (non-toxicity) of CCPs, their potential uses, benefits, and limitations.

• Acted as a liaison for CCP stakeholders and worked to resolve potential concerns as and when they arose.

• Compiled and updated a historical review of CCP research and demonstration projects implemented in the state (see Appendix A).

• Collaborated with ACAA and other national CCP industry organizations such as USWAG to potentially exclude fly ash from RCRA solid waste rules and environmental liability under the Superfund Act.
• Dr. Wolfe and Dr. Butalia received the Barton Thomas Award for the best technical paper titled “The Behavior of Coal Combustion Products in Structural Fills – A Case History” presented at the International Ash Utilization Symposium, October 2001.

• Served on the Barton Thomas Award Committee of the Lexington Ash Conference since 2001.

• Dr. Butalia was awarded the Lumley Research Award for 2001 by OSU. This award by The Ohio State University’s College of Engineering is for exceptional research activity and success in pursuing new knowledge of a fundamental or applied nature.

• Worked closely with the Midwest Coal Ash Association (formerly the Ohio Chapter of ACAA) to advance highway uses of CCPs. Participated in MCAA’s quarterly meetings.

• Expanded networking with Ohio-specific recycling organizations such as the Ohio’s Materials Exchange, Ohio Recyclers Association, and environmental groups.

• Initial Board Member of the Great Lakes By-Products Management Association, 2000. This Great Lakes based organization promotes the land application of by-products through educational and outreach activities. The initial board members included representatives of state agencies, research universities, and recycling organizations.

• Member of Residuals Management Committee of Ohio Water Environment Association since 1999. The residuals management committee consists of representatives of OEPA, ODNR, Ohio Farm Bureau, and OSU. The committee promotes the safe management of wastes and by-products that contribute nutrients and pollutants to the environment.

• Reviewed information on life-cycle cost analysis for CCP projects.

• Monitored the effect of Toxic Release Inventory (TRI) information on the use of CCPs, especially media reports published in the state.
• Expanded current research efforts to include high-volume highway applications, high-value manufacturing uses, high-carbon ash, ammoniated ash, durability concerns, effects of new emission restrictions on CCP characteristics, chemical forms of concern in CCPs and their solubility and mobility in the environment, and long-term pollution potential.

• Provided regular information to CCP stakeholders across the state via e-mail.

• Collaborated with other universities to disseminate in Ohio their newsletters, research findings, and other publications on CCPs.

• Educated the public about the benefits of CCP use rather than landfilling.

• Reviewed several research proposals submitted to United States Department of Energy’s Combustion By-Products Recycling Consortium (CBRC) for funding for FY2000. Written evaluations of the proposals (worth over $1.3 million) were provided to CBRC.

• Reviewed technical research proposals for Illinois Clean Coal Institute on construction applications of fly ash since 2001.

• Reviewed technical proposals for Counter Nuclear Terrorism Office of Center for International Security Affairs at Los Alamos National Laboratory.

• Reviewed several technical proposals for USDA-SBIR on the beneficial uses of industrial by-products in construction applications.
2.4 Major Program Accomplishments

The major accomplishments of the Coal Combustion Products Extension Program are:

- The target goal of 20% FGD material utilization for the state of Ohio by the end of 2005 has been exceeded. The overall CCP utilization of 30% by 2005 has been nearly achieved.
- The program is recognized by Ohio and national stakeholders (regulatory agencies, end-users, utilities, ash marketers, trade organizations, other research universities and centers) as a “voice of trust”.
- The program has established a national and international reputation especially in the beneficial use of fly ash and FGD materials in transportation and other construction market segments.

The program is an active member of USEPA’s Coal Combustion Products Partnership (C2P2), American Coal Ash Association (ACAA), and Midwest Coal Ash Association (MCAA).

In particular, to date the program has:

- Compiled and published CCP generation and beneficial use information for Ohio and the nation.
- Established and maintained the CCPOhio Web site (http://ccpohio.eng.ohio-state.edu)
- Worked with regulatory agencies (USEPA, OEPA, ODOT, ODNR, OSM, ODA, NRCS, etc.).
- Published four Fact Sheets in collaboration with OSU Extension Service and distributed over 4,000 copies.
- Met with central and district offices of OEPA and ODOT.
- Provided assistance in installation of over 200 FGD feeding pads in 12 Ohio counties (over 50,000 tons FGD material).
- Conducted more than a dozen CCP utilization training workshops and open houses.
- Presented over 75 papers and lectures at Ohio and national level seminars and conferences.
- Published over 60 positive publicity articles in the media.
3 RESULTS, DISCUSSION, AND CONCLUSIONS

3.1 Summary

This project report presents the activities and accomplishments of the Coal Combustion Products Extension Program, a technology transfer / research program (DE-FC26-00NT40909), conducted at The Ohio State University from August 1, 2000 to June 30, 2005.

The objective of this program was to promote the use of Ohio coal generated CCPs (fly ash, bottom ash, boiler slag, and FGD material) in beneficial use applications that are technically sound, environmentally benign, and commercially competitive. The project objective was accomplished by housing the CCP Extension Program within The Ohio State University College of Engineering with support from the university Extension Service and The Ohio State University Research Foundation. Dr. Tarunjit S. Butalia, an internationally reputed CCP expert and registered professional engineer, was the program coordinator. The program coordinator acted as liaison among CCP stakeholders in the state, produced information sheets, provided expertise in the field to those who desired it, sponsored and co-sponsored seminars, meetings, and speaking at these events, and generally worked to promote knowledge about the productive and proper application of CCPs as useful raw materials.
3.2 Conclusions

The work carried out under this program involved developing, assessing, and technology transfer of promising CCP use technologies for commercial and end-use sectors.

The program is an active member of USEPA’s Coal Combustion Products Partnership (C2P2), American Coal Ash Association (ACAA), and Midwest Coal Ash Association (MCAA) and is recognized by the CCP industry as a leader promoting the use of CCPs in highway and construction, mine reclamation, agricultural, and manufacturing market segments.

The program accomplishments include:

- The target goal of 20% FGD material utilization for the state of Ohio by the end of 2005 has been exceeded. The overall CCP utilization of 30% by 2005 has been nearly achieved.
- The program is recognized by Ohio and national stakeholders (regulatory agencies, end-users, utilities, ash marketers, trade organizations, other research universities and centers) as a “voice of trust”.
- The program has established a national and international reputation especially for the beneficial use of fly ash and FGD materials in transportation and other construction market segments.
3.3  Recommendations for Future Work

Increase in utilization rates of CCPs for the future is particularly challenging because future regulatory requirements are likely to significantly increase the amount and possibly the types of by-products generated. This adds pressure to CCP use markets but will also present new technical challenges. In particular CCPs of the future are expected to have higher loadings of carbon (including unused activated carbon from mercury control) and may have higher concentrations of mercury and other adsorbed trace elements of concern for human health and the environment.

The CCP Extension Program should be continued at The Ohio State University with increased participation and support from the private sector, especially from the CCP industry (Ohio utilities, marketers, trade associations, and other stakeholders). The primary objective of the CCP Extension Program, the development, assessment, and technology transfer of promising CCP use technologies for commercial and end-use sectors, should focus on increasing the utilization rate of CCPs in Ohio from the current rate of 30% to 40% or more by 2010.

In order to achieve 40% utilization rate of CCPs by 2010 in the state, the following strategy should be implemented. The program should aid the CCP industry through education, technology transfer, and outreach in its efforts to:

- Expand use in proven areas
- Remove or reduce regulatory and perceptual barriers to use
- Develop new or under-used large-volume market applications, and
- Place greater emphasis on FGD byproducts utilization.

The focus of the program must remain on the high-volume uses of CCPs in construction, reclamation, and civil engineering applications. High-value manufacturing uses should receive particular attention. Although the agricultural uses of CCPs have been generally low-volume and value applications for generators, the demand for these uses has gained momentum in the agricultural community. Support for existing agricultural uses should be continued and promising future agricultural uses, such as the use of FGD gypsum as a soil amendment, should be advanced.

The recommendations for future work listed above will promote the use of high-sulfur Ohio coal by providing a positive revenue stream for the large quantities of CCPs (especially flue gas desulfurization material) generated from the combustion of coal and currently landfilled in the state. The end users of CCP beneficial utilization can expect cost savings as compared to the use of conventional natural resources. In particular, the increased use of fly ash to replace cement will significantly reduce CO₂ emissions associated with the use of cement (one ton of fly ash replacing cement will reduce about one ton of CO₂ emissions).
REFERENCES


APPENDIX A:

Historical Review of CCP Research in Ohio
HISTORICAL REVIEW OF CCP RESEARCH IN OHIO
Tarunjit S. Butalia and William E. Wolfe
The Ohio State University

A-1 Introduction

With approximately 90% of Ohio’s electricity being generated from the burning of coal, the state generates approximately 10 million tons of coal combustion products (CCPs) annually. In the past, most of these CCPs (particularly FGD) have been put in landfills or surface impoundments, resulting in largely non-productive disposal of these materials. The utilization of CCPs as raw materials for civil engineering, mineland reclamation, agricultural applications, and manufacturing uses make possible (1) a decrease in the need for landfill space, (2) conserve the natural resources of the state, (3) better and more durable products, (4) allow continued use of Ohio’s high-sulfur coal, (5) significant economic savings for end users, and (6) reduces overall cost of generating electricity. Several CCP projects completed or under progress in the state of Ohio are shown in Figure A-1.

This chapter reviews the progress made in the last few years in CCP (particularly FGD) research by discussing a number of demonstration projects conducted in Ohio to promote the utilization of CCPs. A comprehensive overview of the utilization technologies successfully developed and implemented in the state as well as those under development is presented. A CCP pilot extension program, the first of its kind in any state of the US, which was established at The Ohio State University, is discussed.

A-2 Research on Utilization of CCPs

Over the last ten years, Ohio has become a leader in the development of new technologies for uses of CCPs. This is the result of tremendous cooperation and support by a large number of organizations including: the Ohio Coal Development Office, The Ohio State University, US Department of Energy, American Electric Power, Ohio Edison, Dravo Lime Company, Electric Power Research Institute, US Geological Survey, Ohio Department of Natural Resources, Ohio Environmental Protection Agency, American Coal Ash Association, Midwest Coal Ash Association, Combustion Recycling Consortium, and others.

Several researchers at The Ohio State University participated in a long-term study aimed at characterizing the physical, chemical, mineralogical and engineering properties of dry and wet FGD material and its land application (Stehouwer et al., 1995a, 1998, Wolfe et al., 1992, Adams et al., 1992, Beeghly et al., 1993, 1994, 1995b, Wolfe and Cline, 1995, Dick, et al., 1997, 1999a, 1999b). An extensive review of the state of the art for the characterization and utilization of FGD materials was performed (Stehouwer et al., 1995a, 1998, Dick et al., 1999a, 1999b). Samples were collected from 13 different coal-fired boilers and representative samples of FGD technologies being tested in Ohio were selected for detailed analysis. The technologies included Lime Injection Multistage Burners (LIMB), Pressurized Fluidized Bed Combustion (PFBC), Spray Dryer and Duct Injection. The engineering properties of compacted FGD that were studied
1. Livestock Feeding and Hay Storage Pads* (More than 175 constructed in 12 counties)
2. SR541 Highway Embankment Stabilization*
3. SR83 Highway Embankment Repairs*
4. OSU Truck Ramp*
5. CONSOL Synthetic Road Aggregate Demonstration Project*
6. CONSOL Synthetic Lightweight Block*
7. Caldwell Reclamation Demonstration Project*
8. Fleming Reclamation Demonstration Project*
9. Rehoboth Tests Plots* & Rehoboth Phase I Reclamation Project
10. Broken-Aro Seal Project
11. Roberts-Dawson Underground Injection Project*
12. Conesville Prep Plant Refuse Cover Project
13. Wastewater Treatment Using Reclaimed Mg(OH)₂*
14. Wooster Agricultural Liming Studies*
15. Sorbent FGD Liming Studies*
16. FGD Lined Demonstration Pond Facility*
17. Small-Scale FGD Lined Wetlands*
18. Autoclaved Cellular Concrete Demonstration Project*
19. CCP Pilot Extension Program*

*: Co-funded by the Ohio Coal Development Office

(Source: Ohio Coal Development Office)

Figure A-1: Ohio CCP Projects
included optimum moisture content, density, compressive strength, compressibility, permeability, and swelling potential. These engineering properties were identified to be critical in the design and construction of high volume engineered fills, highway embankments and other earth structures that might be made of compacted FGD. Several other land applications of FGD including, agricultural liming substitute, alkaline amendments for abandoned mine land reclamation, treatment of acidic overburden at active mine sites and toxic mine spoils, stabilization of sewage sludge were identified and studied. The social costs and economic benefits of CCP utilization were presented by Hite (1994) and Hitzhusen (1992).

The swelling potential of FGD was studied by Adams (1992) and Adams and Wolfe (1993) by conducting long-term laboratory swell tests on more than a dozen samples from four power plants representative of FGD processes. Two distinct swelling episodes were observed. The first episode occurred almost immediately after water was supplied to the specimens. This corresponds with the time period during which naturally occurring soils typically experience greatest volume increases due to hydration reactions. The second episode of swelling was observed to begin after 10 or more days had elapsed. A study of the occurrence of swell along with mineralogical changes in FGD material was presented by Stehouwer et al., 1998.

The effects of freeze-thaw cycling can be quite significant in Ohio. Hargraves (1994) and Chen et al. (1997) investigated the effect of thermal cycling on the strength of compacted wet FGD material. Higher water content samples exhibited greater reduction in compressive strength due to freeze-thaw cycling. It was observed that high strengths could be maintained under freeze-thaw cycling if at least 5% lime (dry weight basis) was added to the FGD before compaction and the material allowed to cure for 60 days before being exposed to freeze-thaw. These general recommendations are now used in guidelines for the structural use of FGD in Ohio.

For the use of FGD in highway construction applications, the effect of freeze-thaw cycling on the resilient modulus of PFBC material can be quite significant. Roy (1994) and Wolfe et al. (1997) found that dry FGD products subjected to freeze-thaw cycling could be used satisfactorily as a subgrade material in the construction of low traffic volume roads. Favorable comparison of FGD moduli with published values for materials commonly used in road base construction were seen.

The suitability of dry and wet FGD material as low permeability liners in place of commonly used clay and synthetic liners was investigated by Kim et al. (1992a) and Butalia and Wolfe (1997). Characterization of stabilized FGD showed that laboratory samples could be compacted to achieve permeability coefficients lower than the value typically required by EPA for lining waste containment facilities (1x10⁻⁷ cm/sec). Low permeabilities were measured for samples with high fly ash to filter cake ratio (2:1) and high lime percentage (8%).

**A-3 Ohio Demonstration Projects**

Laboratory tests are typically carried out in a controlled environment under conditions that are generally not the same as those in the field. The obvious next step in the process of characterizing the behavior of FGD materials would be to conduct field demonstration projects to study the suitability of the material and its performance, before a particular utilization
technology can be made commercial for the end user. The Ohio Coal Development Office within the Ohio Department of Development has sponsored many of the field demonstration projects that have been carried out in Ohio. A brief description of these project follows.

**A-3.1 Truck Ramp**

The purpose of constructing a truck ramp was to evaluate the field handling and compaction characteristics of the spray dryer ash generated at Ohio State University’s McCracken Power plan. The truck ramp (17 meter long by 7.5 meters wide and 1.2 meters high) was designed by Ohio State University’s Department of Physical Facilities to provide a location for unloading hard trash (Wolfe and Beeghly, 1993). The ramp was constructed by university maintenance personnel during work schedule breaks in the summer of 1992. Spray dryer ash from the university’s McCracken power plant was used as the primary construction material. The ash was placed within 5% of the optimum moisture content and greater than 90% standard Proctor densities were achieved. The ash did not require any special handling and was constructed using university owned equipment. Tests performed on samples cored from the ramp showed that after a year of service, the water content was considerably higher than the optimum moisture content. Unconfined compressive strength tests conducted on samples cored from the ramp exhibited lower strengths than those achieved in the laboratory. Despite the difficulty in achieving uniform conditions during construction, the ramp performed well with no evidence of failures during subsequent use by university vehicles.

**A-3.2 Livestock Feeding and Hay Storage Pads**

In high rainfall areas such as Ohio, it is desirable to pave livestock feedlot and feeding areas with a durable material like concrete or rock aggregates. Otherwise animals expend considerable amount of energy just to move through slushy organic soil. An inexpensive and reliable technique for stabilizing the feeding areas was identified to be the use of compacted FGD. The site chosen for the first FGD cattle feedlot demonstration project was the Eastern Ohio Resource Development Center in Belle Valley, Ohio. Dry cyclone ash from AEP’s PFBC Tidd plant was used to stabilize the saturated organic in-place soil. The ash was blended into the top 1 ½ feet of the soil and the mixture was compacted to produce a stabilized base. A 1 ½ -2 ½ feet thick layer of compacted ash was then put on top of the stabilized base. All the construction activities were performed by farm personnel using standard farm equipment. Some minor failures were observed when the first round of cattle was brought onto the feedlot. However since the repair of these minor failures, the feedlots have performed well. Additional livestock feeding and hay storage pads were constructed at the EORDC farm in September of 1993 using wet FGD from AEP’s Conesville plant. These feedlots have performed very well with an approximately ¼ to ½ inch annual wear. Ohio EPA was satisfied with the performance of the FGD feeding and hay storage pads and American Electric Power currently has a state wide blanket permit to install (PTI) FGD livestock feedlot and hay storage pads using lime enriched FGD material from its Conesville (CON) and Gavin (GAV) power plants. As long as the conditions in the PTI are met and the thickness of FGD layer is less than 15 inches, no additional approval from Ohio EPA is necessary. The construction of FGD feedlots does not require any special equipment. The cost of an FGD feedlot can be up to 25 percent less than the estimated cost using aggregate and approximately 65 percent less than the estimated cost of concrete. AEP’s plants have generally
provided the material free of cost at the plant with farmers paying for hauling costs. In some cases, the plant has been willing to truck the material to the site if it is in vicinity of the plant. In the summer of 1997, a total of 24 livestock feedlots and hay storage pads ranging in size from 1,500 ft² to 14,000 ft² were constructed in southern and eastern Ohio. Because of the success of these pads, livestock feedlots and hay storage pads constructed with FGD material are in high demand in some parts of Ohio. In 1998, more than 45,000 tons of FGD material was used to construct over 50 FGD pads in 12 Ohio counties.

### A-3.3 Highway Embankment Repairs

A section of Ohio State Route 541 located west of Coshocton that was failing due to a rotational slide was stabilized in the winter of 1993 using PFBC ash generated by AEP’s Tidd plant. The portion of the road affected by the slide was constructed in 1966 over a large fill. The first phase of the project involved the excavation of approximately 310,000 ft³ of soil from above the slip plane. Half of the excavated soil was stockpiled for later use at the site while the rest was transported off site. Several under drains had to be constructed to direct water away from the load bearing portions of the embankment. The second phase involved the placement and compaction of FGD material. Self-loading scrapers delivered the material stocked onsite, as bulldozers spread it evenly over an area 40 feet wide and 100 feet long. The first lift was approximately 2 feet thick and was placed and compacted in one day. Within 12 hours of placement the FGD had gained enough strength for the scrapers to drive over it without leaving any tire tracks. The FGD buttress was constructed up to a height of 13 to 16 feet. The thickness of layers and the amount of water added to the FGD were not strictly monitored. It was observed that the material had a wide workable range and did not have to be mixed with laboratory precision to yield excellent strengths. The original embankment material was then placed on top of the FGD buttress in controlled lifts and the final road surface was constructed. During the first and second phase of the embankment repairs, regular monitoring of the water quality upstream and downstream of the project was done. The variations in pH and total dissolved solids were within the acceptable range of fluctuations associated with the stream. However, water samples taken from underdrains showed a significant rise in sulfates and total alkaline measured as CaCO₃. The volume of stream flow was so much greater than the volume of water being expelled through the underdrains that the total system appeared unaffected by the increase in measured sulfates and CaCO₃ in the leachate. Long-term water quality monitoring of the site is being continued through the third phase of the project. A system of inclinometers, piezometers and deformation measuring gauges were installed at the site and are regularly monitored by ODOT personnel. A more detailed description of the project was presented by Nodjomian (1994), Nodjomian and Wolfe (1994) and Kim et al. (1995).

A second highway embankment repair project involved the stabilization of a portion of Ohio State Route 83 south of Cumberland. A section of the road that had been damaged due to repeated rotational slides was reconstructed using Tidd PFBC ash in 1994. The first phase of the project involved excavation of approximately 380,000 ft³ of embankment soil. Fabric drain boards were installed in a trench dug along the hillside to prevent groundwater from reaching the embankment. The trench was backfilled with compacted FGD in approximately 1 foot thick lifts using a small bulldozer for spreading and a sheepfoot roller for compaction. The second phase of the project was begun by dividing the embankment into four separate sections. Control
sections were established at the north and south end of the site. The control sections were repaired according to standard ODOT procedures by drying, replacing and compacting the stockpiled soil. One test section consisted of a mix of Tidd ash and onsite soil while the third section was constructed using only the ash. The ash-soil section was compacted in lifts of about 8 inches thick while the ash only section could be compacted with much thicker lifts ranging from 1 to 2 feet. Strict control was kept on the moisture content and compacted density and approximately 95% compaction using the standard Proctor was achieved for the four sections. The embankment construction was completed in December of 1994. However, because asphalt plants had closed down for the season, one half of the road was constructed with a 1.5 feet thick compacted FGD wearing course while the other half was made with a 1.5 feet thick layer of stone aggregate. The road was opened to traffic in late December. The ash has performed well over the last four years and has not needed any repairs. Water around the embankment has shown no indication of metals leaching into the surrounding environment. More details on the Ohio SR83 project can be found in Payette et al. (1997) and Civil Engineering News (1997).

The results from these two studies indicated that laboratory precision was not required to achieve excellent strength properties that were more than sufficient for road repair. In order to facilitate the use of FGD in highway embankment repairs, a knowledge-based expert system was developed by Kim et al. (1992b, 1993, 1994).

High volume uses of CCPs such as those for highway embankment applications generally require temporary stockpiling of the material onsite. A 1,500 ton pile of dry LIMB FGD material was constructed in 1992 at a moisture content approaching the optimum water content of 40-50% (Beeghly et al., 1995a). The changes in the properties of the pile were studied for 30 months. Hydration reactions formed gypsum and ettringite creating a crust that stabilized the surface of the pile. This prevented dusting during dry periods and also reduced erosion from the slopes of the pile. However, the runoff from the slopes was minimal. By allowing for the formation of some ettringite to proceed, the expansion of an embankment after placement and compaction of FGD could be minimized. But this would result in a decrease in the cementious capacity of FGD. However, the addition of a small amount of lime just prior to placement should help overcome the loss of cementious reaction that occurred during storage.

A-3.4 Surface Reclamation of Abandoned Mined Lands

Laboratory investigations into the use of various types of FGD materials for mine reclamation applications were carried out by Sutton and Stehouwer, 1992, Stehouwer et al., 1993 and Soto et al., 1993. Greenhouse column studies were carried out by Stehouwer et al. (1995b) to study the element solubility and mobility characteristics of amended minespoils while Stehouwer et al. (1995c) studied the plant growth in minespoils amended with dry FGD. Issues relating to the extension of laboratory tests to field demonstration of minespoil amendments were presented by Dick et al., 1994a.

Several field demonstration projects have been conducted in Ohio that have studied the use of FGD materials for reclamation of highly degraded abandoned mines. An abandoned clay and coal mine near Dover commonly referred to as the Fleming demonstration site was regraded in summer of 1994 and three types of amendment treatment were applied in fall of 1994. The
treatment schemes included separate equivalent applications of limestone, FGD material (PFBC) and a 2.5:1 mixture of FGD and yard waste compost. The treatments were incorporated to a depth of approximately 8 inches. Surface water and drainage water samples were collected. Arsenic was found to be the only trace element that approached a level that would preclude the use of FGD for mine reclamation. The concentrations of all other elements were below the regulation concentrations or loading limit. It was observed that often these metal concentrations were lower than those in the existing overburden spoil that required reclamation. All three treatments improved water quality. The concentration of Boron in the leachate was particularly high from the FGD plots but was below the phytotoxic levels. Surface water quality has remained almost unchanged from 1995. All treatments resulted in water pH of approximately 7. The drainage water samples collected in spring of 1995 showed the FGD plots were neutral while others were acidic (pH of 4-5.5). In July of 1996, the pH values of the treatments whose pH had declined earlier, rose to the neutral level. All the treatments provided complete ground cover. However, all treatments showed a decline in the vegetative growth in 1996 as compared with 1995 with the decline being the greatest for lime treated plots. Long-term effectiveness of the FGD treatments is being studied at the site to learn more about the ecological sustainability of these materials.

Additional mine reclamation field-testing was carried out at Unit II of the Eastern Ohio Resource Development Center near Caldwell, in Southeastern Ohio. The aim of the project was to evaluate the reclamation performance of two wet FGD materials and compare them with borrow soil and sewage sludge mine spoil amendments. The two types of FGD materials used in this demonstration project were generated by the wet lime scrubbers of AEP’s Conesville plant and an experimental scrubber at Cinergy’s Zimmer plant. The original field plot sites had low levels of extractable nutrients. The site was regraded in summer of 1995 and treated with six different types of mine soil amendments. These treatments included: 1) sewage sludge, 2) gypsiferous Zimmer FGD, 3) Conesville FGD, 4) Zimmer FGD mixed with sewage sludge, 5) Conesville FGD mixed with sewage sludge, and 6) red silty clay borrow soil. Details on the applications rates were presented by Kost et al. (1997). All the amendments were rototilled to a depth of about 30-cm. These treatments were applied in the fall of 1995. A flume was installed at the bottom of each plot to collect surface water runoff. Appropriate fertilization of the plots was carried out and they were seeded in fall of 1995 with winter wheat cover crop, and a mix of birdsfoot trefoil, red clover, perennial ryegrass and timothy. Ten seedlings each of white ash, black locust, sycamore and sweetgum were planted in spring of 1996 in each plot. Tree survival, tree height, biomass cover, soil and water quality were monitored. Preliminary results (Kost et al., 1997) of samples collected at the site indicate that all amendments except the sewage sludge alone are effective in decreasing soil acidity within the zone of incorporation. Vigorous herbaceous cover has existed on all the treatments for two years. During this time, herbaceous biomass was reported to be the greatest for plots that were treated with a mixture of Conesville FGD and sewage sludge (Kost, 1997). Additional observations and conclusions for these demonstration projects can be found in Dick et al., 1994b and Stehouwer and Dick, 1997.

A-3.5 Agricultural Liming Substitute

FGD holds promise as a substitute for conventional agricultural lime to adjust the pH of soils (Dick et al., 1993, Sutton et. al, 1994, Stehouwer et al., 1995d). The neutralizing potential of
FGD is due to the presence of calcium carbonate and calcium hydroxide. FGD with a total neutralizing potential of 60% CCE (calcium carbonate equivalency) was used as a limestone substitute at two different Ohio sites. The first field test was conducted at a highly acidic site (pH of approximately 4.6) near Wooster. The amount of PFBC FGD ash applied to the site was varied from 0, 0.5, 1 and 2 times the lime requirement rate as determined by standard soil tests. The FGD ash was applied in the fall of 1992 and alfalfa was planted that season, while corn was planted in spring of 1993. Alfalfa yields increased rapidly compared with untreated control. Corn yields were not significantly increased with the use of PFBC ash. The concentrations of Boron in alfalfa tissue were high for the FGD plots but were below the phytotoxic levels. Tissue concentrations of aluminum and manganese decreased for all samples. Soil acidity was neutralized in the zone of application (0-4 inches) and within one year the pH correction had extended to a depth of about 12 inches. In 1997, another field experiment was begun in Wooster using a sorbent FGD that contained clay. The CCE of the FGD was 46% and it was applied in the spring of 1997 at a rate based on standard soil tests. Alfalfa was planted on the plots. Sorbent FGD significantly increased alfalfa yields as compared to untreated control plots. The yields were more with the sorbent FGD than when the soils were amended with agricultural limestone. This benefit may be due to the presence of trace elements in the FGD material as well as its neutralizing potential. The plots are being monitored to evaluate their long-term performance. Laboratory and field tests have shown that FGD materials with low boron content, low soluble salt content and high acidic neutralizing potential can be utilized as a soil amendment in place of agricultural limestone. Weathering of FGD prior to application results in lower boron and salt content but decreases its neutralizing potential. Application of FGD to the soil using a conventional limestone spinner spreader can cause excessive dusting due to the fine fly ash particles. A drop box spreader can be used instead for spreading the FGD or it could be mixed with other amendments such as organic matter and incorporated into the soil.

A-3.6 Low Permeability Liner

In order to evaluate the performance of FGD as a liner for ponds, manure holding facilities, and wetlands, a full-scale pond facility was constructed in the summer of 1997 at the Ohio State University’s Ohio Agricultural Research and Development Center near South Charleston. The pond capacity is approximately 150,000 cubic ft. and the facility was constructed using wet FGD as the primary liner. The FGD material used for the project was generated by AEP’s Conesville plant using lime slurry injection. A total of approximately 2700 tons of FGD material was compacted in 4-6 inch lifts to obtain an 18 inches thick FGD liner. The design and construction of the FGD-lined facility was presented by Butalia, et al. (1997) and Wolfe and Butalia (1998). First year monitoring of the facility indicates (a) small amount of water is leaching through the field compacted FGD liner (permeability coefficients using full-scale tests are in the range of 10^{-7} cm/sec), and (b) quality of the leachate generally meets the National Primary Drinking Water Regulations (Wolfe et al., 1999). The water in the pond is being replaced with swine manure in September 1998 and the site will be monitored for at least one more year.

A-3.7 Abatement of Acid Mine Drainage

Acid mine drainage (AMD) from abandoned underground coal mines in Ohio causes significant contamination to area streams and lakes. A small abandoned deep mine commonly referred to as
Robert-Dawson mine near Coshocton, Ohio was chosen to study the technical feasibility of injecting cementitious alkaline materials such as FGD into the mine to reduce the environmental degradation occurring due to AMD discharge into the local stream. The effluent at the mine entrances had a low pH (2.8-3.0). Wet FGD generated by AEP’s Conesville plant was pressure grouted into the mine through vertical grout injection holes during the winter of 1997-98. The FGD injection was carried out using regular grouting equipment. Approximately 26,000 tons of FGD material was estimated to be pumped into the underground mine. Two types of FGD grouts were injected into the mine. A thicker mine seal mix (slump of 4-6 inches) was used to seal the down dip areas. The intent was to flood the mine behind the plug so that the water level behind the seal would rise above the coal seam. This would lead to a reduction in AMD production, as no oxygen would be available to oxidize the pyrites in the coal. A similar but much more fluid (slump 8-10 inches) grout mix was injected in some of the up-dip areas of the mine. This was done to neutralize the acidic water in the mine and to coat the bottom of the mine with FGD to cover the pyrite material. A detailed description of the Robert-Dawson AMD abatement project was presented by Mafi et al. (1997). Monitoring of the surface and ground water is being conducted to evaluate the impact of FGD injection inside and outside the deep mine.

A-3.8 Construction Aggregate

A program to investigate the technical and economic feasibility of making construction-grade aggregates from wet FGD is under progress by CONSOL. The characterization and bench scale pelletization of FGD material have been completed. The results of this study have shown that products meeting all AASHTO specifications for Class A highway construction aggregates and products meeting important ASTM specifications for lightweight aggregate can be produced from wet FGD material. The synthetic aggregates were produced using CONSOL’s disk pelletization technology. A large amount of synthetic aggregate was produced and used in two field demonstration projects. The first project involved the construction of a bituminous paving test patch with the synthetic aggregate and the second was the construction of a mine stopping wall using lightweight blocks. The durability of the road aggregate and structural integrity of the lightweight blocks is being monitored.

A-3.9 Ohio CCP Extension Program

Recent research and demonstration projects in Ohio have shown that CCPs can be utilized with proper preparation and oversight. A technology transfer and market development program was established in January 1998 at The Ohio State University. The CCP extension program is the first of its kind in any state in the US. It aimed to move technologies for utilization of CCPs (particularly FGD material) from the research and demonstration phase into the marketplace with the establishment of a statewide Coal Combustion Products Coordinator. Bringing CCP use technology to the marketplace has both economic direct benefits and indirect and societal benefits for Ohio. The direct benefits are most easily quantified and are generally what drive the adoption of a new product or technology. Direct economic benefits include those realized by both the producer of the CCPs and the end user. The producer benefits if the cost associated with support of beneficial uses is lower than that of landfilling or other disposal means. The end user benefits if the CCP application results in lower cost than conventional application. The CCP
Coordinator acts as a liaison among the parties interested in CCP use, producing fact and information sheets and providing expertise in the field to those who wish it. The Coordinator also sponsors or co-sponsors seminars, meetings, and speaking at these events, and generally works to promote knowledge about the productive and proper application of these products as useful raw materials. A significant component of this program is the compilation of this market development study, which includes identification of CCP production in Ohio, and the estimated and potential markets for these CCPs particularly in highway/road construction and related civil engineering uses, mine reclamation and agricultural applications. The principal sponsors of the CCP extension program are the Ohio Coal Development Office and The Ohio State University.

A-4 References

Civil Engineering News, 1997, Coal Combustion Product is Good for Highway Use, November.


Hargraves, M.D., 1994, The Effect of Freeze-Thaw Cycles on the Strength of Flue Gas Desulfurization Sludge, M.S. Thesis, The Ohio State University, Columbus, Ohio.


Hitzhusen, F.J., 1992, Social Costs and Benefits of Recycling Coal Fired Power Plant FGD By-Products, Department of Agricultural Economics and Rural Sociology, The Ohio State University, Columbus, Ohio.


Kim, S.H., 1994, A Decision Support System for Highway Embankment Design Using FGD By-Products, Ph.D. Dissertation, The Ohio State University, Columbus, Ohio.


Nodjomian, S.M., 1994, Clean Coal Technology By-Products Used in a Highway Embankment Stabilization Demonstration Project, M.S. Thesis, The Ohio State University, Columbus, Ohio.


Roy, B.L., 1994, The Effect of Freeze-Thaw Cycling on the Resilient Modulus of Clean Coal Technology By-Products, M.S. Thesis, The Ohio State University, Columbus, Ohio.


Stehouwer, R.C., Sutton, P., and Dick, W., 1993, Growth of Fescue on Acid Minespoil Amended With FGD and Sewage Sludge, American Society of Agronomy Meetings, Cincinnati, Ohio, November 7-12.


Wolfe, W.E., Cline, J.H., 1995, A Field Demonstration of the Use of Wet and Dry Scrubber Sludges in Engineered Structures, Proceedings of 11th International Symposium on Use and Management of Coal Combustion By-Products (CCBs), Orlando, Florida, Jan 15-19, American Coal Ash Association and Electric Power Research Institute, EPRI TR-104657, V. 1, p. 17(1-10).


APPENDIX B:

Journal Articles, Book Chapters, and Conference Presentation Articles


Butalia, T.S., Wolfe, W.E., Use of Clean Coal Technology Products in the Construction of Low Permeability Liners, ACAA-CBRC-WRAG Fall Meeting, Denver, Colorado, October 4-6, 2004


Butalia, T.S., Vories, K., Coal Combustion Products: Opportunities for Reclamation Partnerships, COAL-GEN, Columbus, Ohio, August 6-8, 2003


Butalia, T.S., Beneficial Use of Solid By-Products from Air Pollution Control Devices at Coal Fired Facilities, Ohio Air Pollution Control Research Symposium, Toledo, Ohio, October 25, 2002


Butalia, T.S., Market Opportunities for Land Application of Ohio Coal Combustion Products, Beneficial Use of By-Products: Regional Issues, The Ohio State University, Columbus, Ohio, November 30 – December 1, 2000
APPENDIX C:

Conference Organization

Member, Advisory Board of International Pittsburgh Coal Conference, 2003-2006

Co-Chair, Conference Program Committee, 22nd Annual International Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, September 12-15, 2005

Chair and Organizer, Session on Coal Utilization By-products, 22nd Annual International Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, September 18-25, 2005

Member, Technical Program Committee, 2005 World of Coal Ash, Lexington, Kentucky, April 11-15, 2005

Co-Chair, Conference Program Committee, 21st Annual International Pittsburgh Coal Conference, Osaka, Japan, September 13-17, 2004

Chair and Organizer, Session on Coal Utilization By-products, 21st Annual International Pittsburgh Coal Conference, Osaka, Japan, September 13-17, 2004

Member, Technical Program Committee, 2003 International Ash Utilization Symposium, Lexington, Kentucky, October 20-22, 2003

Chair, Session on Concrete, 2003 International Ash Utilization Symposium, Lexington, Kentucky, October 20-22, 2003

Co-Chair, Conference Program Committee, 20th Annual International Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, September 15-19, 2003

Chair and Organizer, Session on Coal Utilization By-products, 20th Annual International Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, September 15-19, 2003


Chair and Organizer, Session on Coal Combustion By-Products Utilization, 19th Annual International Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, September 23-27, 2002

Co-Chair, Session on Wave Propagation and Dynamics, 2nd Biot Conference on Poromechanics, Grenoble, France, August 26-28, 2002
Chair and Organizer, Session on Coal Combustion By-Products Utilization, 18th Annual International Pittsburgh Coal Conference, New Castle, Australia, December 3-7, 2001

Chair, Session on Construction Products, 2001 International Ash Utilization Symposium, Lexington, Kentucky, October 22-24, 2001
APPENDIX D:

Program Funding

United States Department of Energy $55,647
Ohio Coal Development Office $113,601
The Ohio State University $94,720
American Electric Power $10,000
ISG Resources $10,000
Carmuese North America $10,000
American Coal Ash Association $10,000
Midwest Coal Ash Association $ 4,000
Total Project Cost $307,968
APPENDIX E:

CCP Extension Program Fact Sheets

Coal Combustion Products Extension Program - Program Overview, Coal Combustion Products Extension Program Fact Sheet, The Ohio State University, 2004


Butalia, T., Wolfe, W., Dick, W., Limes, D., Stowell, R., Coal Combustion Products, The Ohio State University Extension Fact Sheet, AEX-330-99, The Ohio State University, Columbus, Ohio.

Butalia, T., Dyer, P., Stowell, R., Wolfe, W., Construction of Livestock Feeding and Hay Bale Storage Pads Using FGD Material, The Ohio State University Extension Fact Sheet, AEX-332-99, The Ohio State University, Columbus, Ohio.
Coal Combustion Products Extension Program
Program Overview

Department of Civil and Environmental Engineering and Geodetic Science & OSU Extension Service
470 Hitchcock Hall, 2070 Neil Avenue, Columbus, Ohio 43210
Phone: 614-688-3408, Fax: 614-292-3780, Email: http://ccpohio.eng.ohio-state.edu

What is Coal Combustion Products (CCP) Extension Program?

The objective of the CCP Extension Program is the development, assessment, and technology transfer of promising CCP use technologies for commercial and end-use sectors.

The program advances the technically sound, environmentally safe, and commercially competitive uses of CCPs in many interdisciplinary applications. The focus of the program is on high-volume highway and related civil engineering uses, and mine reclamation applications. The high-value manufacturing uses receive particular attention. Although the agricultural uses of these materials are generally low-volume and value applications for generators, the demand for these uses has gained momentum in the agricultural community across the state. Support for existing agricultural uses has continued and promising future agricultural uses are supported.

Approximately 21% of CCPs generated in the state were utilized in 1997. The goal of CCP Extension Program is to work with Ohio CCP stakeholders to increase the overall CCP utilization rate to more than 30% by the year 2005. Flue gas desulfurization (FGD) material utilization rate for the state in 1997 was 8.4%. The program aims to increase FGD material utilization for Ohio to more than 20% by the year 2005. The increased utilization rates are expected to be achieved through increased use of CCPs for highway, mine reclamation, agricultural, manufacturing, and other civil engineering uses.

Program Implementation

A qualified CCP expert, Dr. Tarunjit S. Bansal, P.E., is the statewide coordinator of the CCP Extension Program at OGU. The program is a collaborative effort of the OSU Extension Service and College of Engineering. In general, the coordinator works to promote knowledge about the productive and proper application of CCPs as useful raw materials in highway applications, mine reclamation, and agricultural uses. The major activities implemented by the program are:

- Work with regulatory agencies to produce environmental and technical guidelines and standards for CCP use
- Work towards overcoming regulatory, technical, economic, marketing, and public perception barriers to use of CCPs
- Prepare educational materials for end-users which provide detailed instruction of various uses of CCPs and serve as a resource person to end-users
- Conduct workshops to train end-users and others in the advantages and proper application of CCPs
- Demonstrate the use of CCPs via preparation of informational materials, papers, presentations, press releases, web site, etc.
- Maintain an Ohio-specific CCP database, update it regularly, and provide information to stakeholders
- Serve as a liaison among CCP stakeholders in the state
- Work with generators, manufacturers, and others to produce value-added products from or with CCPs that will benefit the use of Ohio coal, and provide technical, environmental, economic, and other benefits to the state of Ohio.

Duration

The program is being implemented for a period of over 4 years (October 2000 to June 2005)

Program Funding

<table>
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<tr>
<th>Organization</th>
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<td>Ohio Coal Development Office</td>
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<td>$94,720</td>
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<td>United States Department of Energy</td>
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<td>Carmesse North America</td>
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<td><strong>Total Project Cost</strong></td>
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</table>
Coal Combustion Products Extension Program

Fact Sheet

Department of Civil and Environmental Engineering and Geodetic Science & OSU Extension
470 Hitchcock Hall, 2070 Neil Avenue, Columbus, Ohio 43210
Phone: 614-688-3408, Fax: 614-292-3780, E-mail: http://ccphio.eng.ohio-state.edu

Landfill Cost Model for Disposal of Coal Combustion Products

Tarunjit Butalia, Ph.D., P.E., The Ohio State University
Gary Brendel, P.E., GAI Consultants, Inc.
David Lewandowski, CONSOL Energy Inc.

Approximately 100 million tons per year of Coal Combustion Products (CCPs) are generated in the United States. As existing coal-fired power plants install flue gas desulfurization (FGD) systems to meet environmental requirements, the quantity of CCPs generated in the US will increase significantly.

CCPs typically generated include fly ash, bottom ash, boiler slag, and FGD materials. An overview of these CCP types can be accessed at http://ohiolimes.osu.edu/sex-duct0210.html.

Most CCPs are currently being landfilled. This disposal option is currently favored due to its perceived low cost. However, most of the existing landfills were developed when environmental laws regulating their design and operation were less stringent, sites were plentiful, and public opposition was virtually nonexistent. All of these factors have changed, resulting in significantly higher costs for landfills constructed today. However, many generators may not be completely aware of these higher costs and thus do not consider other options for disposal or beneficial use. With existing landfill space being filled rapidly, CCP generators need a tool to help them make up-to-date, informed environmental and economic decisions for disposal of CCPs when existing landfill space is exhausted.

Direct Relevance

The computer model presented in this fact sheet quantifies the cost of new CCP landfill development, which may ultimately encourage generators to consider the alternative beneficial use of these materials. The cost components include capital, operating and maintenance, and post-closure costs. The landfill costs generated by the model provide a benchmark against which use options can be compared. Thus, the model can be a valuable tool to agencies and organizations working towards the beneficial use of CCPs.

Deborah Kosmack, CONSOL Energy Inc.
Robert Barnes, P.E., Trumbull Corporation

The program provides the user with the option of treating the landfill as a commercial operation and analyzing costs as an investment decision and establishing a landfill disposal price to meet a specified return on investment. For example, the user can specify the project life, inflation rate, tax rate, and a desired internal rate of return (IRR). The landfill disposal fee ($/ton) required to meet this investment objective would then be calculated. Costs are generated for staged construction (one cell at a time) or for the entire landfill all at once.

The model is also applicable to existing landfills, for which the operating and maintenance, and post-closure costs are relevant.

Computer Program Overview

The landfill design and cost computer model predicts the capital, operating and maintenance, and post-closure costs of CCP landfills. The model is constructed with a high degree of flexibility to provide accurate estimates under a variety of possible scenarios. The program encompasses regulations specific to the states of Ohio (OH), Pennsylvania (PA), and Kentucky (KY). It includes design and cost algorithms to account for different land topographies and CCP types (fly ash, bottom ash, and FGD materials). It also includes design options to meet anticipated future landfill design regulations and cost escalation factors to maintain its accuracy over a long period of time.

The computer model is available in Microsoft EXCEL 2000/Visual Basic for Applications (VBA) software platform. A copy of the program and its use’s manual can be accessed at: http://ccphio.eng.ohio-state.edu/ccphio/

Each input field variable has a suggested range of values as well as a default value. The user can choose a default value or input a specific value, from the range of suggested values. This provides a significant amount of flexibility in the
program so that it can be used by experts as well as those new to the subject.

**Program Input**
The computer model input module consists of the following components:
- State regulations (specific to OH, PA, KY, or input specific options for other states)
- Quantity of CCPs (life of landfill, quantity of CCPs generated annually or estimated from power plant characteristics)
- Scrubber inputs if program is to calculate the quantity of CCPs (choice of no scrubber, forced oxidation, natural oxidation, thiosulfate lime, or lime spray dryer; operating details for each scrubber type, etc.)
- Landfill geometry selection (choice of topographies of flat terrain, valley fill, and side hill)
- Capital costs (direct capital costs, such as site preparation, roads, drainage systems, installation of layers, erosion and sediment control, leachate collection, sediment pond, closure activities, etc.; and indirect capital costs, such as site selection and characterization, permitting fees, site engineering, purchase of land, etc.)
- Operating and maintenance costs (groundwater, leachate, and surface water monitoring and management; waste characterization; intermediate cover; general site maintenance; placement of materials in landfill; transportation; compliance certifications; management and supervisory costs; etc.)
- Post-closure costs (number of years of monitoring required; groundwater, leachate, and surface water monitoring and management; maintenance of cover system; deed notification; final certification; etc.)
- Economic input (year equipment installed, total ordinary tax rate, depreciation rate, inflation rate, bond rate, chemical engineering cost index for current year)

Defaults and suggested ranges are provided for all inputs.

**Program Output**
The output of the computer program is an itemized list of capital costs, operating and maintenance costs, as well as post-closure costs for the landfill configuration chosen. Each of these costs are also available on a $ per ton and $ per cubic yard basis. The economic analysis consists of a yearly (from opening of landfill to end of post-closure) listing of working capital, cash margin, tax, investment, and cash flow.

**Illustrative Example**
Illustrations 1 and 2 show an example of the input data and results for a test case generated for a landfill with a life of 20 years built on a flat terrain under Ohio Class III code regulations for a 510 MW power plant. The program output summarizes the design parameters, capital costs, operating and maintenance costs, post-closure costs, and total calculated costs based on desired IRR.
Illustration 1: Critical Input Data for Example Case
Flat terrain under Ohio Class III code with geomembrane for liner

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>State:</td>
<td>Ohio</td>
</tr>
<tr>
<td>Code:</td>
<td>Class III – with geomembrane</td>
</tr>
<tr>
<td>Geomembrane:</td>
<td>Primary liner – PVC,</td>
</tr>
<tr>
<td></td>
<td>Secondary liner – none,</td>
</tr>
<tr>
<td></td>
<td>Cap – none</td>
</tr>
<tr>
<td>Drainage type:</td>
<td>Aggregate/geotextile</td>
</tr>
<tr>
<td>CCP Produced:</td>
<td>Unknown volume of CCPs produced</td>
</tr>
<tr>
<td>Coal:</td>
<td>12,500 Btu/ft, 2.5% sulfur, 10% ash</td>
</tr>
<tr>
<td>Power Plant:</td>
<td>510 MW, 9600 Btu/kWh, 65% capacity factor</td>
</tr>
<tr>
<td>Scrubber:</td>
<td>Natural Oxidation</td>
</tr>
<tr>
<td>Geometry:</td>
<td>Flat fill - input height: 40 feet,</td>
</tr>
<tr>
<td></td>
<td>depth of excavation: 2 ft,</td>
</tr>
<tr>
<td></td>
<td>input width: 2030 feet</td>
</tr>
<tr>
<td>Operating Life:</td>
<td>20 years</td>
</tr>
<tr>
<td>Construction Stages:</td>
<td>1</td>
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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Number of Monitoring Wells:</td>
<td>10</td>
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<tr>
<td>Waste type/location:</td>
<td>FGD/20% from stockpile &amp; 80% from plant bin</td>
</tr>
<tr>
<td>Hauling:</td>
<td>Public paved roads with 2 round trips/hr using triaxle truck</td>
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<tr>
<td>Management, supervisory, and</td>
<td>Management and engineering design as percent of total O&amp;M cost: 12.5%</td>
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<tr>
<td>overhead costs as percent of</td>
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<tr>
<td>total O&amp;M costs:</td>
<td>15%</td>
</tr>
<tr>
<td>Post-Closure period:</td>
<td>15 years</td>
</tr>
<tr>
<td>Remedial costs as percent of</td>
<td>10%</td>
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<tr>
<td>total post-closure costs:</td>
<td>15%</td>
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<tr>
<td>Internal Rate of Return:</td>
<td>15%</td>
</tr>
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</table>

Illustration 2: Results for Example Case

SUMMARY FOR CAPITAL COSTS

<table>
<thead>
<tr>
<th>Landfill Design Calculations</th>
<th>Value</th>
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<tbody>
<tr>
<td>Landfill Life Volume</td>
<td>cubic yd 5,388,183</td>
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<tr>
<td>Landfill Life Volume</td>
<td>ton    6,437,828</td>
</tr>
<tr>
<td>Type of Landfill Selected</td>
<td>yard   Flat Fill</td>
</tr>
<tr>
<td>Waste Fill Height</td>
<td>ft     30.5</td>
</tr>
<tr>
<td>Fill Height Below Surface for Flat Terrain</td>
<td>ft     0</td>
</tr>
<tr>
<td>Final Landfill Height - Above Surface for Flat Terrain</td>
<td>ft     44.00</td>
</tr>
<tr>
<td>Final Landfill Height - Above Surface for Valley or Side Slope</td>
<td>ft     Valley or Side not Selected</td>
</tr>
<tr>
<td>Acreage for CCPs</td>
<td>acre   95.95</td>
</tr>
<tr>
<td>Total Acreage Needed for CCPs and Support of Landfill</td>
<td>acre   4102.37503</td>
</tr>
<tr>
<td>Surfaced Area of Liner</td>
<td>acre   2030.00</td>
</tr>
<tr>
<td>Front Width of Landfill</td>
<td>ft     2030.00</td>
</tr>
<tr>
<td>Back Width of Landfill</td>
<td>ft     2030.00</td>
</tr>
<tr>
<td>Length of Landfill</td>
<td>ft     2573.71</td>
</tr>
<tr>
<td>Depth of Material Removed</td>
<td>ft     2.00</td>
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Economic Calculations
| Site Selection:                | $100,000     |
| Site Characterization:         | $100,000     |
| Permit Application/Permits:    | $50,000      |
| Design/Engineering:            | $150,000     |
| Total Indirect Costs:          | $410,000     |

Land Purchase: $599,704

Total Site Preparation: $2,473,306

Total Roads: $108,000

Total Drainage: $2,199,724

Total Installed Layers: $14,297,912

Total Sediment Pond Liners: $372,952

Total Closure Activities: $388,770

TOTAL CAPITAL COST OF LANDFILL: $21,251,277

Total Capital Cost: dollars/ton: $3.30

54
### Illustration 2 – Results for Test Case Continued

#### SUMMARY FOR OPERATION & MAINTENANCE COSTS

<table>
<thead>
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<td>Landfill Life Length (years)</td>
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<tr>
<td>Landfill Life Volume (cubic yd)</td>
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</tr>
<tr>
<td>Landfill Life Volume (tons)</td>
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<tr>
<td>Total Groundwater Monitoring</td>
<td>$458,000</td>
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<tr>
<td>Total Leachate Monitoring</td>
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<td>Total Surface Water Monitoring</td>
<td>$324,000</td>
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<td>Total Waste Characterization</td>
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<td><strong>TOTAL MONITORING AND CHARACTERIZATION COSTS</strong></td>
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<tr>
<td>Total O&amp;M of Leachate Collection/Treatment Systems</td>
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<td>Total O&amp;M of Groundwater Management Systems</td>
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<td>General Site Maintenance</td>
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<td><strong>TOTAL MAINTENANCE</strong></td>
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<td><strong>TOTAL TRANSPORTATION</strong></td>
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<td>Compliance Certifications</td>
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<td>Certification of Closure</td>
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<td><strong>In-Annual Monitoring, Operating &amp; Maintenance, Management, Supervisory and Overhead Costs as Percent of Total O&amp;M Costs</strong></td>
<td>$21,936,313</td>
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<tr>
<td>%</td>
<td>15.00%</td>
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<tr>
<td>Profit as Percent of Total O&amp;M Costs</td>
<td>$2,889,444</td>
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<tr>
<td>%</td>
<td>10.00%</td>
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<td><strong>TOTAL MONITORING, OPERATING &amp; MAINTENANCE</strong></td>
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<td>Total O&amp;M Cost: dollar/cubic yard</td>
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#### SUMMARY FOR POST-CLOSURE COSTS

<table>
<thead>
<tr>
<th>Description</th>
<th>Subtotal</th>
<th>Total</th>
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<tr>
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<td><strong>TOTAL MAINTENANCE</strong></td>
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<td>Deed Notation</td>
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#### SUMMARY OF TOTAL COST FOR LANDFILL

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<tr>
<td>Total Capital, O&amp;M, and Post-Closure Costs: yr 2001 dollar/cubic yard</td>
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#### SUMMARY OF TOTAL COST FOR LANDFILL ADJUSTED FOR IRR

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<td>Total Capital, O&amp;M, and Post-Closure Costs: yr 2001 dollar/cubic yard</td>
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<td>Total Capital, O&amp;M, and Post-Closure Costs: yr 2001 dollar/ton</td>
<td>$16.33</td>
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</table>
Coal Combustion Products

Mariette Butalia
Research Specialist
Civil and Environmental Engineering and Geodetic Science

William Wolfe
Professor
Civil and Environmental Engineering and Geodetic Science

Warren Dick
Professor
Ohio Agricultural Research and Development Center

Dana Limes
Environmental Services
Waste Management Section

Richard Scowell
Assistant Professor
Food, Agricultural and Biological Engineering

More than half of the electricity generated in the United States is produced by coal-fired facilities. The Clean Air Act Amendments of 1990 require many utilities, especially those in the Midwest, which burn high-sulfur bituminous coal, to reduce sulfur dioxide emissions. This has resulted in the generation of large amounts of coal combustion products (CCPs). These products include fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) material (see Table 1). In 1996 approximately 800 million tons of coal were burned in the United States to produce electricity. This led to the generation of over 90 million tons of CCPs. The total tonnage of CCPs generated surpassed Portland cement and iron ore production in the United States and ranked behind only crushed stone, sand, and gravel among non-fuel mineral sources.

Figure 1 shows the amount of each type of CCP generated in 1996 and the amount that was utilized. Overall, one-fourth of the CCPs generated were utilized while the rest were disposed of mainly by landfiling. Only 7% of the FGD material generated in the United States was utilized. With Phase 2 of the Clean Air Act Amendments of 1990 going into effect in the year 2000, the amount of FGD material produced in the United States may increase by an order of magnitude to almost 200 million tons, thus exceeding the production of all other CCPs (Kalyoncu, 1996). Increasingly stringent emission requirements will result in a further increase in the production of CCPs as long as electric utility industries continue to burn coal to produce electricity.

CCPs in Ohio

Nearly 90% of the electricity produced in Ohio is generated from burning of coal, and the state generates about 12% (11.6 million tons) of all CCPs produced in the United States. These products, produced in large quantities, have traditionally been disposed of in expensive, non-productive landfills. Many of these products are separated from other product streams. If treated and applied correctly, these materials have versatile properties that make them suitable raw materials for many uses ranging from highway/civil engineering applications, mine land reclamation, to agricultural applications. The recycling of CCPs as raw materials in applications that are environmentally sound,

<table>
<thead>
<tr>
<th>CCP type</th>
<th>Characteristics</th>
<th>Texture</th>
<th>Amount typically generated per ton of coal burned (lbs.)</th>
<th>Major constituents</th>
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<tbody>
<tr>
<td>Fly ash</td>
<td>Non-combustible particulate matter removed from stack gases</td>
<td>Powdery, silt-like</td>
<td>160</td>
<td>Si, Al, Fe, Ca</td>
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<tr>
<td>Bottom ash</td>
<td>Material collected in dry bottom boilers, heavier than fly ash</td>
<td>Sand-like</td>
<td>40</td>
<td>Si, Al, Fe, Ca</td>
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<tr>
<td>Boiler slag</td>
<td>Material collected in wet bottom boilers or cyclone units</td>
<td>Glasy, angular</td>
<td>100</td>
<td>Si, Al, Fe, Ca</td>
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<tr>
<td>FGD material</td>
<td>Solid/wet-solid material obtained from flue gas scrubbers</td>
<td>Pile to coarse (dry or wet)</td>
<td>350</td>
<td>Ca, S, Si, Fe, Al*</td>
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</tbody>
</table>

* Fixed FGD material is a mixture of filter cake (Ca, S), fly ash (Si, Fe, Al), lime, and water. Major constituents of gypsum quality FGD material are Ca and S.
technically safe, and commercially competitive should lead to a reduction in the practice of landfilling these raw materials. Their continued utilization will lead to: 1) a decrease in the need for landfill space, 2) conservation of the natural resources of the state, 3) reduction in the cost of producing electricity, 4) lower electricity cost for consumers, and 5) substantial savings for end-users of CCPs.

**Uses of CCPs**

Leachate tests conducted on CCPs have shown that the leachate from these materials generally meets the national primary drinking water standards. Fly ash, bottom ash, boiler slag, and FGD material are being used today as raw materials in many different application technologies. Table 2 shows the different uses for CCPs.

**Summary**

When treated and applied correctly, coal combustion products can be put to multiple productive uses in civil engineering, mine reclamation, and agricultural applications. The use of these materials in ways that are technically sound, environmentally benign, and commercially competitive can result in significant savings for CCP end-users, coal-fired facilities, and the people of the state of Ohio.

**More Information**

A pilot Extension program is currently in place at The Ohio State University to move CCP technologies and processes from the research and development phases into the marketplace. More information on the use of CCPs can be obtained from the Internet web site [http://ccpohio.eng.ohio-state.edu](http://ccpohio.eng.ohio-state.edu) or by contacting the Extension program coordinator:

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**Bibliography**


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<table>
<thead>
<tr>
<th>CCP Type</th>
<th>Potential areas of major use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash</td>
<td>Cement replacement in concrete/grout, structural fill, flowable fill, waste stabilization, surface mine reclamation, soil stabilization, road base, mineral filler</td>
</tr>
<tr>
<td>Bottom ash</td>
<td>Concrete block, road sub-base, snow and ice control, structural fill, waste stabilization, pipe bedding, cement manufacture</td>
</tr>
<tr>
<td>Boiler slag</td>
<td>Blasting grit, roofing granules, snow and ice control, mineral filler, construction backfill, water filtration, drainage media</td>
</tr>
<tr>
<td>FGD material</td>
<td>Wallboard, stabilized road base/sub-base, structural fill, surface mine reclamation, underground mine injection, livestock pad, low permeability liner, synthetic gypsum raw material, liming substitute, soil conditioning, synthetic aggregate, sludge stabilization</td>
</tr>
</tbody>
</table>


Acknowledgments

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For more information on the use of CCPs, please visit the "CCPOhio" web page at: http://ccpohio.org.ohio-state.edu

Visit Ohio State University Extension's WWW site “Ohioline” at: http://ohioline.ag.ohio-state.edu

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Keith L. Smith, Associate Vice President for Ag. Adm. and Director, OSU Extension
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Construction of Livestock Feeding and Hay Bale Storage Pads Using FGD Material

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Excessively muddy conditions at livestock feeding and watering areas can have detrimental effects on farm operations. The animals have to expend a considerable amount of energy just to move through mud. This can result in higher feed costs as well as reduced weight gain by livestock. Hay bales stored on wet ground can take on moisture, leading to early deterioration and as much as 50% spoilage. Avoidance of muddy conditions can result in increased animal performance and significant monetary savings for producers, as well as a cleaner farm environment.

To avoid muddy conditions, it is often desirable to construct a stable, impermeable, and sloped surface so that water drains off rather than accumulates on the area. Flue Gas Desulfurization (FGD) material is currently being used as an inexpensive and reliable product in the construction of feeding pads. It is also being used for constructing pads for hay bale storage so that the bales can be protected from mud and moisture. Pads constructed of FGD are not as strong, hard, or durable as concrete, but for these applications, FGD pads improve conditions of the area substantially for usually far less expense than concrete.

The objective of this publication is to provide livestock producers, landowners, and supervising agency personnel with an overview of the use of FGD product in pad construction. This fact sheet includes information on pad installation, regulatory constraints, pad location and sizing, maintenance and repair, and economic issues.

What is FGD?
The removal of sulfur dioxide from flue gases at coal-fired facilities results in the generation of large amounts of Flue Gas Desulfurization (FGD) material. The FGD material may be dry or wet depending on the desulfur-
Livestock Feeding Pads

Concrete or stone aggregate typically has been used for constructing livestock feeding pads. However, research conducted at The Ohio State University has shown that construction of pads using compacted FGD product is an inexpensive and reliable alternative. The first cattle feeding pad using FGD material was constructed in 1992 at the Eastern Ohio Resource Development Center (EORDC) near Belle Valley in Noble County. Cyclone ash from American Electric Power's (AEP) Tidd plant was used. Additional feeding (Figure 1) and hay

Figure 2. Hay bale storage pad

Figure 3. Hay bale storage on constructed FGD pad
bale storage pads (Figure 2) were constructed at the FORDC farm in 1993 using wet FGD material from AEP’s Conesville plant. The success of these demonstration projects led to statewide approval of FGD pads for these two applications using AEP’s lime-enriched FGD product. In the summer of 1997, twenty-four livestock feeding and hay bale storage pads, ranging in size from 1,500 square feet to 15,000 square feet, were constructed in eastern and southeastern Ohio. In 1998, more than 150 FGD pads were constructed in 12 counties in Ohio.

**Hay Bale Storage Pads**

FGD pads may be constructed for storing hay bales (primarily large, round bales as shown in Figure 3). Appropriate pad design allows bales to be placed so that precipitation drains away from them relatively quickly. Rain and snow will collect in troughs formed by bales whose sides touch, so leave a gap between adjacent rows of bales. Drain water from the pad by either crowning the pad across its length or constructing the pad with some continuous fall toward one end; provide 1% or greater grade in either case. Side-slope should be small compared to the lengthwise grade—or water will collect along the uphill side of rows/bales. If the side-slope and lengthwise grade are similar for a site that is suitable otherwise, plan to systematically place gaps every couple of bales along each row to reduce ponding around the bales (and adjust pad length accordingly).

Approach areas may be included along the perimeter of the hay bale storage—along ends of the pad if bales will be typically handled by their ends or along sides of the pad if handled by their sides (latter case shown in Figure 3)—to improve access to the bales. If used, approach areas should be wide enough to allow bale-handling equipment to access the nearest bales, including a turn, without dropping a wheel off the pad. Use concrete rather than FGD in any areas where handling equipment is likely to make frequent turns and in areas which will accommodate more than just bale-handling equipment. Material will rapidly slough off the pad surface under intensive use by equipment.

Reasonable grades must be maintained on a pad for safe operation of bale-handling equipment, especially along the length of a pad when bales are to be handled from the side. Also consider operator safety at locations associated with bale transport, such as turns in drives and places where bales are likely to be elevated. Consult manufacturer recommendations provided for your equipment before investing resources into a questionable site.

**Regulatory Issues**

OEPA approved the statewide construction of FGD pads on June 25, 1997. A PTI (Application No. 07-0037) was issued to AEP for providing quicklime-enriched FGD product from its Conesville and Gavin power plants for the construction of livestock feeding and hay bale storage pads. As long as the conditions outlined in the PTI are followed, landowners and livestock farmers generally do not have to obtain additional authorization from OEPA. This fact sheet has been prepared to be in conformity with the PTI issued by OEPA.

**Sources of FGD**

The material to be used in the construction of the pads is the fixed FGD product generated at coal-fired power plants which has been enriched with an adequate amount of fly ash and extra quicklime so that the total lime content is 4-6%. Lime-enriched FGD product that has been approved for constructing pads is currently available from AEP’s Conesville power plant (Coshocton County) and Gavin power plant (Galia County).
Gavin FGD material typically has a lower moisture content than Conesville FGD material. The material is currently available free of cost at the plants. The Conesville plant may be willing to transport the material free of cost within Coshocton County.

**Pad Location**

Runoff will occur from FGD pads, just as if they were made of concrete. This runoff needs to be controlled to avoid polluting nearby waterways. Livestock feeding and hay bale storage pads constructed of lime-enriched FGD material need to be located on a farm such that a healthy farm environment can be maintained. As per OPEPA restrictions, FGD pads may not be located:

- within 100 feet of a stream, pond, or wetland unless runoff control structures are in place;
- within a 100-year floodplain unless the area is protected with a control structure;
- within 300 feet of a well for drinking water (human or livestock) unless the potentially affected property owner provides a written statement to OPEPA describing the use of the well water and signifies approval of the pad;
- within 5 feet of a seasonal high water table;
- within 1,500 feet of a public water supply well;
- within the delineated boundaries of an OPEPA-endorsed wellhead protection plan area; and
- at a location which would create a nuisance condition or cause an adverse impact to public health or the environment.

Additionally, pads must not be located in areas which are identified by a soil survey as subject to flooding, or likely to convey manure runoff directly to a waterway (via a cow-path, ditch, drive, etc.) regardless of the separation distance.

Installing control structures such as earthen berms, smalt earthen dikes, etc., can accommodate many of these siting restrictions. Local Natural Resources Conservation Service (NRCS) and Soil and Water Conservation District (SWCD) personnel can assist in the planning of control structures and may be able to identify sources of monetary assistance.

If animals will be confined on a pad rather than allowed to access the pad at their leisure from a pasture to eat or drink, the area may be considered to be a feedlot and, by definition, an "Animal Feeding Operation." In order to limit the liability of producers and retain the protections of the OPEPA P11 strategies for controlling runoff from such pads need to be designed by a professional and implemented on the farm prior to construction.

**Sizing**

The size of the FGD pad selected can significantly affect the cost and efficiency of the livestock operation. The pad should be large enough to accommodate the present animal population as well as allow for future additions to the herd as projected by the owner or operator of the facility. However, an excessively large pad can result in unnecessarily high construction costs. A livestock feeding pad should be large enough to accommodate the animals that are eating or drinking, plus about 6 feet along the perimeter to allow the animals to conveniently move to and from the feeder or waterer. A worksheet is included to size hale bale storage pads. Feeding pads should be sized in conjunction with development of a runoff-control strategy. For illustrative purposes, an FGD pad that is 100' x 100' and approximately 12"-15" thick will require 500-600 tons of FGD product.

An open pad does not usually constitute a controlled manure storage facility in Ohio and FGD product is not currently approved as a construction material for manure storage. Therefore, any scraped manure/material should
Worksheet for Sizing Hay Storage Pads and Calculating FGD Needs
Dimensions may be rounded to the nearest ft., areas to nearest 10 sq. ft.

1) Size of bales to be stored on the pad = _______ ft x _______ ft.
   length diameter or width

2) Number of bales to be stored on the pad = _______
   typical maximum
   If, over the next few years, hay storage needs are expected to increase, use a projected number of bales (and reduce costs of transporting construction equipment twice).

3) Select the number of bales to be stored per row = ________ bales per row
   (placed end-to-end/lengthwise as shown in Figure 3) typical maximum

4) Number of rows = _______ bales + _______ bales per row
   => _______ rows
   (round up)
   Bales are assumed to be stored in a single layer (not stacked). To adjust the number of rows required, change the number of bales in each row and repeat this calculation. Or, divide the number of bales by the desired number of rows to obtain the number of bales per row.
   Revised calculation (if desired): ________ bales + ________ = ________

5) Pad length = 3 ft. + (_______ bales per row x _______ ft. x 1.1) + _______ ft. - _______ foot
   edge bale length end approach width or another 3-ft edge

6) Pad width:
   Width used by bales = (_______ bales per row x _______ ft.) + (_______ ft. - _______ x 2 ft.) = _______ feet
   # of rows bale width # of rows gap
   Total pad width = 3 ft. + _______ ft. + _______ ft. = _______ feet
   edge width for bales side approach width or another 3-ft edge
   To adjust the maximum width of a pad significantly at either point, repeat Step 5, adjusting a different number of bales per row or number of rows, and repeat Steps 3-6.

7) Storage pad area = _______ ft. x _______ ft. = _______ sq. ft.

8) Access area (for bale-handling traffic onto and off of the pad only):
   Access area = _______ ft. x _______ ft. = _______ sq. ft.

9) Total pad area = _______ sq. ft. + _______ sq. ft. = _______ sq. ft.

10) FGD requirement = _______ sq. ft. + 16 sq. ft. per ton = _______ tons
SAMPLE

Worksheet for Sizing Hay Storage Pads and Calculating FGD Needs

Dimensions may be rounded to the nearest ft., down to nearest 5 sq. ft.

1) Size of bales to be stored on the pad = \( 5 \text{ ft.} \times 6 \text{ ft.} \)

2) Number of bales to be stored on the pad = 50
   typical maximum
   
   If, over the next few years, hay storage needs are expected to increase, use a projected number of bales (and reduce costs of transporting construction equipment twice).

3) Select the number of bales to be stored per row = \( 6 \) bales per row
   (placed end-to-end/lengthwise as shown in Figure 3)
   typical maximum

4) Number of rows = \( \frac{50}{6} = 8.3 \) \( \Rightarrow \) 9 rows
   (round up)
   
   Bales are assumed to be stored in a single layer (not stacked). To adjust the number of rows required, change the number of bales in each row and repeat this calculation. Or, divide the number of bales by the desired number of rows to obtain the number of bales per row.
   
   Revised calculation (if desired): \( 50 \) bales + 5 rows = 10 bales/row

5) Pad length = 3 ft. + ( \( \frac{10}{5} \) ft. \times 5 ft., or 1.1 ft. + \( \frac{3}{5} \) ft.) = 67 feet

6) Pad width:
   
   Width used by bales = \( \frac{5}{5} \) ft. + \( \frac{6}{5} \) ft. \( \left( \frac{5}{5} \right) \times 2 \) ft. = 38 feet
   
   Total pad width = 3 ft. + \( \frac{38}{5} \) ft. + 16 ft. = 57 feet
   
   To adjust the dimensions of a pad significantly at this point, return to Step 3, specify a different number of bales per row or number of rows, and repeat Steps 3-6.

7) Storage pad area = \( \frac{61 \text{ ft.} \times 57 \text{ ft.}}{\text{pad length}} = 3,480 \text{ sq. ft.} \)

8) Access area (for bale-handling traffic onto and off of the pad only):
   Access area = \( \frac{16 \text{ ft.} \times 12 \text{ ft.}}{\text{Ave. length of access}} = 190 \text{ sq. ft.} \)

9) Total pad area = \( \frac{3,480 \text{ sq. ft.} + 190 \text{ sq. ft.}}{\text{storage pad area}} = 3,670 \text{ sq. ft.} \)

10) FGD requirement = \( \frac{3,670 \text{ sq. ft.} + 16 \text{ sq. ft. per ton}}{\text{total pad area}} = 229 \text{ tons} \)
be transported to a designed storage facility or to a field for application as soon as feasible.

Livestock access areas can also be constructed of FGD material if animals will regularly use the areas. An access area is defined as land which immediately surrounds a pad and will reasonably only support traffic that is directly associated with the pad. Use of FGD to construct drives, lanes, and other trafficways is not allowed under current Ohio EPA permit authority.

Installation Procedure

FGD pads need to be constructed between May 1 and August 30 to minimize potential freeze/thaw effects. This will allow the FGD material to cure for a sufficient amount of time before being exposed to freezing weather. If the FGD material is too dry or too wet, it cannot be compacted properly. The moisture content of the material during compaction should range from 40-55%. For successful installation of FGD pads, the following procedure is suggested as per the PTI issued by OEPAG:

- Comply with the location restrictions specified in the Pad Location section.
- Excavate the site to expose the subgrade. Clear the area of any vegetation, sod, manure, organic soil, and debris.
- Establish a reasonable grade for positive drainage. A maximum slope of 3-5% is suggested. Slopes in excess of 8% can cause excessive erosion of the pad.
- Compact the exposed subgrade with compaction equipment (roller) or hauling equipment (loaded truck, tractor) prior to placement of FGD. If excessively weak or wet soils are encountered, remove the soil, backfill with FGD and compact.
- Place FGD material within 3 days of delivery to the site (Figure 4). If the FGD material delivered to the site is too wet to be compacted, let the FGD material remain in a pile for a day and then apply it to the pad site. Spreading of FGD does not facilitate drying of the material.
- Spread FGD to the appropriate depth by using a bulldozer, tractor blade, or grader (Figure 5). Break large items using dozer blades, scrapers, rollers, etc.
- Add additional lime, quicklime fines, or cement to the FGD product if so desired by the owner of the facility. No additional lime needs to be added to the FGD product.
- Pads should be made in layers, whenever possible, to improve pad durability. FGD material that has less than 50% moisture content (Gavin FGD material) should be compacted in three layers (up to 5 inches each) or at least two layers (up to 7.5 inches each). Due to less desirable workability, wetter FGD material (Conesville FGD) may be formed into a pad as a single layer provided extra attention is dedicated to thoroughly consolidating the material.
- Compact each layer (extremely important) as shown in Figure 6 to consolidate the FGD material and obtain a uniform, solid surface. Use a smooth-drum or sheepfoot roller or equipment with equivalent compactive effort (earthmoving equipment or heavy farm tractor). Remove any boulders of FGD that cannot be easily broken and worked into the layer.

Table 1. Cost Summary for FGD Pads Constructed in Gallia County

<table>
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<tr>
<th>Project ID</th>
<th>Area (ft²)</th>
<th>Actual FGD cost</th>
<th>Estimated aggregate cost</th>
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</tr>
<tr>
<td>6</td>
<td>5,424</td>
<td>$2,888</td>
<td>$3,563</td>
<td>$7,073</td>
</tr>
</tbody>
</table>

Average cost $2,742 $3,727 $7,854
Ratio to FGD cost 1 1.36 2.86
FGD savings as % 26.4% 65.1%
• Rough up the top 1/2 to 1 inch of each layer/lift prior to the placement of the next layer to provide adequate bonding between the two layers.

• Keep the total thickness of the compacted FGD pad less than 15 inches.

• Smooth-roll the top layer to provide a uniform, solid surface. A 1/2-inch to 1-inch layer of gravel may be rolled into the finished surface to improve traction. If farm equipment will be operated on the pad area often, strengthen the top layer with 5% quick lime, Portland bag cement, or 15-20% lime kiln dust (added at the site).

• Feather-roll (down to zero depth) the edges of the pad. Otherwise use earthen or steel edging forms.

• Keep the pad surface moist for a minimum of 7 days to allow for proper curing. Cover the pad with straw or sheets of plastic.

• Keep livestock off the pad for at least 30 days following the initial 7-day curing period.

• Install fence posts, if needed, within 30 days of constructing the pad. Otherwise the FGD material may become too difficult to penetrate.

The two most important criteria for successful installation of an FGD pad (see Figure 7) are the moisture content of the FGD product and the compactive effort used to consolidate the material.

**Maintenance**

Periodically, manure or waste feed will need to be removed from a pad. This is usually carried out using a skid loader or box scraper. Pad life is expected to depend on the amount of use by livestock and equipment. While scraping the pad, caution should be taken not to remove excess amounts of FGD. To extend a pad’s life, leave a thin cover layer over the pad surface rather than gouging into the FGD when scraping the pad. Incidental amounts of FGD that are removed during scraping may be spread with the manure. The pad is expected to lose about 1/4 to 1/2 inch of FGD material every year due to these incidental losses. After a few years of service, if the top surface of the pad shows small patches or holes, repair by filling in with inexpensive ready-made cementitious materials. If local failures on the top surface are extensive, then clean the surface thoroughly and put an additional layer of compacted FGD on top of the existing pad. If for any reason the pad needs to be removed from the farm, then the FGD product will become subject to waste disposal requirements and must be taken to a licensed landfill.
Economics

The cost of using the FGD product for constructing livestock feeding and hay bale storage pads compares favorably with conventional materials such as concrete or rock aggregate. Twenty-four FGD pads were constructed in the summer of 1997 in Gallia and Coshocton counties. A cost analysis was carried out for six of the FGD pads installed in Gallia County. The cost summary comparison is listed in Table 1. Estimates were prepared using cost guidelines developed by NRCS and local prices for equipment, operators, materials, and transportation in the Gallia County area. On average, an FGD pad constructed in Gallia County cost approximately $2,750 with approximately half of the cost for trucking of FGD and the rest for site work and material placement. The total cost of the FGD pads was about 26% less than the estimated cost for construction using aggregate and about 65% less than the estimated cost for concrete pads. For Coshocton County, where the FGD material may be delivered free to the site by the Conesville plant, the projected savings compared with aggregate and concrete would be 63% and 83% respectively. This represents a significant amount of monetary savings for farmers installing pads using the FGD product.

Contact Information

More information on the use of FGD product for constructing livestock feeding and hay bale pads can be obtained from the following:

- For technical information, contact American Electric Power’s Geotechnical Engineering Section at (614) 223-2940.
- For regulatory guidance, contact Ohio EPA’s Division of Surface Water at (614) 644-2025.

Construction of FGD livestock pads needs to be a part of an overall farm plan. NRCS personnel can assist interested farmers in developing a farm conservation plan. Owners and operators of livestock facilities should contact their county Extension agent, Soil and Water Conservation District, NRCS personnel and the following:

- To use FGD product of AEP Conesville Plant (Coshocton County)
  Bill Jewett, AEP: (740) 829-4121 or 4083
  Rob Senita, AEP: (740) 829-4034
- To use FGD product of AEP Gavin Plant (Gallia County)
  Doug Workman, AEP: (740) 367-7331

Farmers must provide the following information at the time of placing the order for the FGD product:

- contact and phone number
- owner and operator of farm
- address of farm
- dimensions of the feeding/storage pad
- estimated quantity of FGD product needed
- estimated pick-up date

The manufacturer of the FGD product shall provide to the user the following documents:

- a copy of Ohio EPA approved specification sheet
- a copy of the product Material Safety Data Sheet
- documentation that the FGD product meets Ohio EPA’s “nontoxic” criteria

Summary

Construction of livestock feeding and hay bale storage pads using quicklime-enriched flocculated FGD product is a reliable and economical solution to excessively muddy conditions in high rainfall areas such as Ohio. This fact sheet covered the characteristics of FGD material and the regulatory issues involved. It included recommendations for siting, sizing, installing, and maintaining pads as well as performance data of FGD pads. An economic analysis of pads constructed in Gallia County was presented. The inexpensive and reliable use of this material can result in significant cost savings for farm operators and owners while improving the quality of farm operations in Ohio.

More Information

More information on the uses of FGD and other coal combustion products can be obtained from the following Internet web site:

http://ccpobio.eng.ohio-state.edu

or by contacting the pilot Extension program project coordinator:

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Bibliography


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http://ccpohio.eng.ohio-state.edu

Visit Ohio State University Extension’s WWW site “Ohioline” at:

http://ohiolinc.ag.ohio-state.edu

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