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COAL COMBUSTION BYPRODUCTS: POTENTIAL IMPACT OF A HAZARDOUS WASTE DESIGNATION ON SMALL BUSINESSES IN THE RECYCLING INDUSTRY

HEARING

BEFORE THE

COMMITTEE ON SMALL BUSINESS
UNITED STATES
HOUSE OF REPRESENTATIVES

ONE HUNDRED ELEVENTH CONGRESS

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SUBCOMMITTEE ON RURAL DEVELOPMENT, ENTREPRENEURSHIP AND TRADE HEARING ON COAL COMBUSTION BYPRODUCTS: POTENTIAL IMPACT OF A HAZARDOUS WASTE DESIGNATION ON SMALL BUSINESSES IN THE RECYCLING INDUSTRY

Thursday, July 22, 2010

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SMALL BUSINESS,
Washington, DC.

The Subcommittee met, pursuant to call, at 10:00 a.m., in Room 2360, Rayburn House Office Building, Hon. Heath Shuler [chairman of the Subcommittee] presiding.

Present: Representatives Shuler, Bright, Dahlkemper, Luetkemeyer, and Thompson.

Chairman SHULER. This hearing is called to order.

The subcommittee has called this hearing so that members might learn more about coal ash, the small businesses that turn coal ash into useful products and the concerns that these businesses have about the proposed Federal regulations that they believe may have a negative effect on their industry. We hear a lot of terms today in this hearing, like CCB, CCR, CCP and CCW. In essence, all these refer to coal ash.

What we will focus on this hearing are the types of coal ash that are beneficially reusable.

Coal ash contains elements that can be harmful to the environment and to human health unless it is properly stored or disposed of.

The environmental community has long called for increased Federal regulations of coal ash in order to ensure greater protection. I am in complete agreement with this concept. The EPA has recently issued two proposals for regulating coal ash. One would regulate coal ash as a solid waste and would provide very limited Federal enforceability and may not provide adequate protection of the environment and human health. The other would list coal ash as a special waste under the Hazardous Waste Subtitle in the Resource Conservation and Recovery Act, Subtitle C.

The second option is one that we will focus on today's hearing since it has generated great concerns among small businesses across this country. These businesses, many of which are represented here today, have reason to believe that regulating coal ash under Subtitle C, even as a special waste, will open recycling oper-

ations to added litigation and a stigma that will discourage the products and use of the products made with recycled coal ash.

Some of these small businesses believe that these negative effects are already occurring within their industry. If the prediction of those in the coal ash recycling businesses are accurate, EPA regulation of coal ash under Subtitle C will greatly harm a multi billion dollar industry that provides thousands of American jobs and often results in reduced waste disposal and net carbon emissions.

I am eager to hear their testimony today and the testimony from the EPA witness, Lisa Feldt, who will hopefully be able to shed additional light on this subject.

I want to thank all the witnesses for being here today.

And I now yield to the ranking member, Mr. Luetkemeyer, for his opening statement.

Mr. LUETKEMEYER. Thank you, Mr. Chairman, for holding the hearing on this very important topic, one that I know is particularly pressing for many small businesses in both of our districts and all throughout the country.

The Environmental Protection Agency will soon make a decision on how to regulate coal combustion byproducts, CCBs. EPA offered two regulatory options for classification of CCBs under the Resource Conservation and Recovery Act. It is my belief that classification as a hazardous waste under Subtitle C will be a disaster to the small businesses that recycle CCBs.

Some CCBs have industrial uses, while others are essentially waste byproducts. One of the most useful CCBs is coal fly ash, which is a fine, powdery CCB produced by coal-fired electricity generators. Coal fly ash is incorporated in concrete.

Montana's Hungry Horse Dam, completed in 1953, was one of the first applications in which fly ash was used. Since then, at least 100 major locks and dams using fly ash have been constructed under the direction of the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation or private engineering firms.

In light of the CCB spill disaster at the Tennessee Valley Authority's Kingston facility, I understand EPA's raising concerns about the handling and storage of CCBs. We all want appropriate precautions to be taken and for the public health and welfare to be protected. However, slapping a hazardous label on fly ash and other CCBs without sound scientific evidence almost surely will eliminate their ability to be used in a beneficial manner by industry. Such a designation will also impose severe financial hardship on an industry dominated by small businesses employing tens of thousands of people throughout the United States, including my home State of Missouri.

According to EPA's own analysis, approximately 13.4 tons of coal ash are used in concrete or cement production annually. EPA maintains that the regulation of these uses will not be changed, so the agency did not examine what effects would result on the recyclers because of the proposed rule. But the hazardous designation could kill ash recycling enterprises that generate $5 billion to $10 billion a year in revenue for coal-burning utilities. In addition to the revenue lost, generators of CCBs will have to find a place for 60 million tons that now fill abandoned mines, incorporate into concrete or shore up eroding highway embankments.

Should EPA decide a hazardous waste management regime is necessary, the CCBs would quickly overwhelm the capacity of currently available hazardous waste landfills. A hazardous designation would raise the cost of coal ash disposal from $5 or $10 a ton to $150 a ton, a total of $10 billion to $15 billion more per year.

Nor would that situation be helped by the recycling of CCBs. To the extent that regulations, especially under Subtitle C, impose additional costs to generators, they will pass those costs on to the beneficial reusers of CCBs. Increased regulation of CCBs would force recyclers to pass increased costs on to consumers, reduce prices to meet those of lower cost suppliers, or abandon the use of CCBs altogether. A rational producer will ultimately select the third option in an effort to ensure that its competitive position in the marketplace is not damaged. This only will increase pressure on landfills or surface impoundment storage of this waste.

During the past 20 years, the EPA has considered whether to determine that CCBs should be hazardous waste, and each time they have found they should not. Nothing in the physical or chemical characteristics of these products has changed. What has changed is the fact that surface impoundments regulated under the Clean Water Act containing CCBs failed. That regulatory failure should not result in the regulation of CCBs as hazardous waste.

It is my belief that the designation of fly ash as a hazardous waste is counter to the goal of sustainability or even good for the environment. CCBs increase the durability of the Nation's infrastructure, thereby requiring less reconstruction and associated runoff of pollutants from construction sites. Fly ash is commonly accepted and used worldwide, and its use is a key strategy to sustainable construction, reducing hazardous waste disposal needs and limiting creation of greenhouse gasses. CCBs increase the durability of the Nation's transportation infrastructure and double its useful life. The EPA has not considered any of this in its propped rule.

If EPA continues down this path and resists the call from 121 Members of Congress to abandon its preferred course of action—designating CCBs as hazardous waste—I believe that there will be sufficient bipartisan support to take legislative action to address EPA's regulatory overreach.

Again, thank you, Mr. Chairman, for holding this hearing. I look forward to hearing from the witnesses examining possible solutions.

With that, I yield back.

Chairman SHULER. I would like to thank the ranking member for his opening remarks.

And now I would like to recognize Mr. Bright from the great State of Alabama.

Mr. BRIGHT. Thank you, Mr. Chairman. It is great to be here. Very quick opening statement, and I am really looking forward to the testimony today. But I do want to thank you and the ranking member for holding this very important hearing. And I do consider it an extremely important hearing for my State and the people that I represent.

As many of you know, coal combustion waste recycling generates an estimated $5 billion to $10 billion dollars in revenues for enti-

ties which produce CCW nationwide. Thousands of small businesses benefit from the beneficial use of CCW, which creates jobs and provides economic growth at a much-needed time in our history.

In my home State of Alabama, the combination of ready-mixed, asphalt, and raw cement integrates around 450,000 tons of coal ash use in a slow year; it would be up to around 600,000 tons in a good market.

With that said, this issue is important to me and many other districts throughout our great country, and I hope to learn more today about what we can do to protect the beneficial usage of coal ash.

I want to thank our witnesses today. I am looking forward to your testimony. And I really appreciate your agreeing to come here and testify before this panel.

And I really do look forward to your testimony and also our panel two testimony a little later today.

So thank you very much, Mr. Chairman. I return it back to you.

Chairman SHULER. I thank the gentleman from Alabama.

Our first witness is Ms. Lisa Feldt. Ms. Feldt is a deputy assistant administrator of solid waste and emergency response in the U.S. Environmental Protection Agency.

This office develops guidelines for the land disposal of hazardous waste and underground storage tanks.

Mrs. Feldt, you will be recognized for 5 minutes.

STATEMENT OF LISA FELDT, DEPUTY ASSISTANT ADMINISTRATOR, OFFICE OF SOLID WASTE AND EMERGENCY RESPONSE, U.S. ENVIRONMENTAL PROTECTION AGENCY

Ms. FELDT. Thank you, Mr. Chairman and members of the subcommittee. As you indicated, my names Lisa Feldt. I am the deputy assistant administrator for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response. Thank you for the opportunity to testify today on EPA's coal combustion residuals—I will try to stay away from the acronyms—regulatory development activities. I will summarize my testimony, but I ask that my entire written statement be submitted for the record.

Let me start by saying that we understand there are differences of opinion regarding how to regulate coal combustion residuals, or CCRs, as we commonly refer to them.

I can assure you that we want to strike the right balance. We want to get this right. We must base our decisions and foundation in the law and the science. We must provide protection to human health and the environment in a way that also takes into account the significant environmental and economic benefits of beneficial use of CCRs, or coal combustion residuals.

EPA Administrator Lisa Jackson has indicated her support for continued safe beneficial use as we evaluate CCR regulatory options for safely managing the disposal of the coal combustion residuals in our rulemaking effort. We seek a national dialogue on EPA's proposal for addressing the risk, as we do in all our rulemaking efforts, for addressing the risk of managing CCRs under the Resource Conservation and Recovery Act.

During the development of our proposal, administrator Jackson and Assistant Administrator for Solid Waste Emergency Response

Mathy Stanislaus met with representatives from States, from businesses, including those who beneficially use CCRs and are on your next—some of them on your next panel, and many environmental groups, as well as local communities.

Including in a good faith effort to help get the data and information needed to strike the right balance in our rulemaking effort, we want to ensure that our ultimate decision—and let me say our ultimate decision, we have made no decision yet—is made based on the best available science and data and is taken with the fullest possible extent of public input.

While our efforts are underway, I am mindful of the importance of allowing the rulemaking process to run its course, of waiting for the expected wide range of public comments and not appear to prejudging the issues associated with this complex rulemaking. Therefore, I may not be able to answer all the questions you have to me so that we allow that process to continue.

Regarding EPA's proposal, we have two alternative regulatory options and are currently taking comments on a wide cross section of issues. I would like to stress that under both regulatory approaches proposed by EPA, the agency would leave in place the current exemption for beneficial use of CCRs and thus would not alter the regulatory status of CCRs that are beneficially used. Large quantities of CCRs are beneficially used today in concrete, cement wallboard, and other contained applications that EPA believes would not involve exposure to the public to unsafe contaminants. Responsible environmentally sound beneficial uses of CCR conserve resources, reduce greenhouse gas emissions, lessen the need for waste disposal units and provide significant domestic economic benefits.

We are seeking comment in the rule on all forms of beneficial use, as we have heard many different viewpoints. We remain committed to encouraging environmentally sound beneficial use of coal combustion residuals.

CCRs that are disposed of, though, are one of the largest waste streams generated in the United States. CCRs contain constituents, such as arsenic, cadmium and mercury, which can pose threats to public health and the environment if improperly managed and disposed. Thus proper management of these waste streams—not the beneficial use of CCRs, but the waste streams that are disposed of—is essential to protecting public health and the environment.

Prior to our recent regulatory proposal, EPA, as has been acknowledged here, has had a long history of regulatory efforts regarding CCRs. In May of 2000, EPA issued its regulatory determination that CCRs did not warrant regulation as a hazardous waste under Subtitle C of RCRA. EPA also concluded at that time that Federal regulations of a nonhazardous waste under Subtitle D of RCRA was appropriate. With respect to beneficial uses, EPA determined that the beneficial use of CCRs did not pose a risk that required Federal regulation.

Since EPA's May 2000 determination, we have continued to gather additional information that supports the need for regulation of CCR disposal. The catastrophic failure of the Tennessee Valley Authority surface impoundment retaining wall in Kingston Tennessee

in December 2008 and the release of more than 5 million cubic yards of coal ash into Emory and Clinch Rivers and surrounding areas has highlighted this issue for all of us.

EPA determined that regulatory efforts had to be designed to also prevent future catastrophic releases as well as preventing other types of environmental damage associated with the disposal of CCRs in landfill and surface impoundments.

As I mentioned before, EPA's proposal, issued on June 21st of this year, includes two options. One alternative would list CCR when destined for disposal in landfill or surface impoundments as special waste subject to regulation under Subtitle C of RCRA, which would create a comprehensive program of federally enforceable regulations.

Under the second alternative, EPA would regulate the disposal of CCR under Subtitle D of RCRA as a solid waste by issuing national minimum criteria and would be enforced through citizen suits or by the States.

One of the issues that commenters have raised to EPA is that any regulation of CCRs under Subtitle C of RCRA will impose a stigma on their beneficial use and thus significantly curtail these beneficial uses. EPA has questions regarding this assertion and stated in the preamble to the proposed rule that if Subtitle C of RCRA was selected as the regulatory option, the management and disposal of CCRs would become more expensive and thus beneficially using CCRs would become attractive economically.

Past experience with other waste regulated under RCRA Subtitle C suggests the increased cost of disposal as a result of Subtitle C regulations would create a strong economic incentive for increased beneficial use.

However because this issue has been raised and because EPA strongly supports the environmental sound beneficial use of CCRs, EPA is seeking comment and data on this issue.

In closing, I want to assure the members of the subcommittee and all of the witnesses appearing here today that EPA takes the concerns raised about the risk to human health and the environment; the potential impact on businesses large and small; on beneficial use; and a host of other issues regarding our CCR proposal.

Thank you, Mr. Chairman. That concludes my prepared remarks. I will be pleased to answer any questions you or the subcommittee members have.

[The statement of Ms. Feldt is included in the appendix.]

Chairman SHULER. Thank you, Mrs. Feldt, for your remarks.

Obviously, one of the most important things from this subcommittee is the impact on small businesses.

And I have a letter here that is from the American Coal Ash Association asking the Administrator Jackson to do a formal review of potential impacts on the ruling of small businesses that recycle coal ash has.

I have another letter here from the EPA denying that request.

Did the EPA ever survey whether the small businesses in the recycling industry would be harmed by Subtitle C designation of coal ash?

Ms. FELDT. Yes. We did a small business analysis for the entities that we were preparing to regulate, which was the small power

companies. We did an evaluation of the small business impact to the industry that we were proposing to regulate under either option Subtitle C and Subtitle D.

We conducted extensive economic analysis in those areas to support the proposed rule. EPA analyzed the direct impacts on small facilities that are subject to the rule, the small power plants, 26 percent, and found no significant economic impact on a substantial number of small entities.

Since we are not regulating beneficial use under this rule, consistence with agency guidance, these facilities were not included in our small business analysis.

We welcome through this rulemaking process any costs of impact data and recommend that it be submitted during the comment period and for the record.

Chairman SHULER. Thank you.

So from the small, the recyclers, there was no nothing, no survey done when it comes to the recyclers.

Ms. FELDT. Again, we, the beneficial use of CCRs was exempt and remains exempt under either proposal, so we did not do a specific analysis on the recyclers.

As I mentioned, we met with many of the recycling community and trade associations, including the American Coal Ash Association, and continue to receive their input and look for any specific comments and impacts through this rulemaking process.

Chairman SHULER. Executive Order 12866 says that this analysis should include an assessment of all costs and benefits, including indirect cost. Why didn't the EPA use this ruling for more indirect recyclers to use this ruling under the executive order?

Ms. FELDT. EPA conducted under the Executive Order, which is on regulatory impacts, significant analysis on the proposed rule. This included the estimation of direct cost to the utilities, ancillary costs to government, groundwater protection benefits to the public, avoided structural failure benefits to the public, the indirect effects on beneficial use, the indirect effects on electricity prices and distributional effects on several groups, including small businesses, minorities and low-income populations.

There were several effects that EPA could not quantify for this analysis. For instance, EPA did not quantify the ecological benefits of this rule. Even for those effects, EPA discussed the issues qualitatively.

To the extent that EPA did not evaluate any direct or indirect effects or was unable to quantify the effects for the proposed rule, we would welcome, again through the comment process and the rulemaking, for the record submission of any additional information or data to help us as we develop the final rule.

Chairman SHULER. But that is allowing the industry to respond, which is great, and I think the industry will respond.

But what about the actual, the working of the EPA? I mean, it is part of the responsibility of EPA to go and look at this indirect. It says all, and I have it capitalized here. And I don't know, it is probably not capitalized and underlined within the regs, but this is the impact of the recyclers. I mean, this is the small businesses.

And the reason I ask this so much is because you have two proposals, one under C and one under D, and they are quite broad,

from one extreme to the other, very loose regulations to no to little regulations from the Federal Government, and very stringent regulations and almost to the point that its still under Subtitle C; that means that special waste is still going to be considered a hazardous waste. But I don't know about you, but if it is considered hazardous waste and it is under Subtitle C, then that to me is, that will have a huge exact impact on the small businesses.

So you have two proposals that are, in my estimation and others, is on opposite ends of the spectrum. And so often we need to come to that common ground. Hopefully that is where we can get to today, is to come to that common ground. But I think it would really be helpful if the EPA would conduct that indirect cost to the recyclers, indirect impact to the recyclers going forward.

Is that something that could be done during this period of time, or is it already passed that during the public opinion that it can't be addressed?

Ms. FELDT. Again, we excluded beneficial use from the regulation under either C or D.

We did look at indirect effects on the beneficial reuse from a bounding perspective, and I can get you some additional information that we looked at from that perspective.

But certainly any comments that are submitted, either via this committee or through public comment process, we will look at and analyze in our final decision.

Chairman SHULER. In the recycling process, especially in concrete, a huge amount, and I think the gentleman from Alabama and the ranking member also alluded to it, a huge amount of the coal ash is used in recycling back into cement and concrete.

Was the, during this process in conducting the regulation, the proposals that you have, was carbon emissions ever a part of how much savings and lowering emissions based upon using this as a recycled product? And what is the—because it costs a lot of—there is a lot of carbon produced and energy consumed based upon the production of concrete and cement. And so was that ever taken into consideration during the process?

Ms. FELDT. Yes, we looked at, in our benefits analysis, we looked at both the carbon footprint reduction as well as the disposal capacity, energy usage; all those factors we looked at in our beneficial analysis. And those discussions are found in the proposal.

Chairman SHULER. Why do you feel that there is so much discrepancy between the two proposals? I may be naive, but to me, it looks like it is pretty broad within the two proposals.

Ms. FELDT. Yes. The C proposal basically provides Federal regulation with specific Federal enforceability.

The prime differences of the D regulation is the Federal enforceability aspect.

But we want to consider comments on both. And both of them will require liners. Both of them require groundwater monitoring. Both of them require some form of corrective action in setting either a C or D proposal.

It is really the enforceability issue, which is one of the key concerns for—but why we want to gather comment on both options. So, again, for the record, during this national dialogue and national review of the rule, we request all interested parties to submit their

comments on either the D or the C and what their perspectives are and what the data is to support either C or D. The agency has not taken a position one way or the other on that.

Chairman SHULER. Under Subtitle D, does the EPA have authority and direct regulations to regulate the CCB disposals?

Ms. FELDT. As I mentioned, we have, in the rule itself, we have extensive discussion on the differences and concerns raised between regulation under Subtitle D.

Under Subtitle C it is a full cradle-to-grave management process.

You know the prime issue is the enforceability. The Subtitle D is enforced either through citizen suits or by the States that promulgate Subtitle D regulations.

Chairman SHULER. I went to the TVA site in Kingston, and I certainly saw the amount of devastation—is probably the best words to use—most of that problem obviously was how they, it was almost like stacking jello. It was so wet when they were disposing of it into the sites, that it was like stacking jello. And at a certain point, when the stack gets so high, something has to fall.

So I certainly saw the devastation and the environmental impact it is going to have for not just a couple years but probably very, very long term to be able to see the impact.

Hopefully we will get a chance to ask some more questions, but at this point in time, I will yield to the ranking member, Mr. Luetkemeyer for his questions.

Ms. FELDT. Thank you.

Mr. LUETKEMEYER. Thank you, Mr. Chairman.

Mr. Chairman was very thorough in his discussion here. Let me just follow up on a couple of things.

My concern is that we are trying to regulate something that back in 2000 EPA found that there was no problem for, so that we reached the decision that it is not warranted to regulate. And as a result, there was no risk to human health or the environment. There were no cases of damage to human health or the environment that has been identified.

Now we are looking at doing that. And what has changed?

Ms. FELDT. Let me just be clear. Our 2000 regulatory determination did propose regulation under Subtitle D as a solid waste. Since that time, we have gathered new information. We have damage cases that are part and parcel and discussed in the rule, and we can provide for the record that talk about the, not only the catastrophic failure that happened at Kingston—

Mr. LUETKEMEYER. Wait, wait, wait. That is an impoundment problem. That is not a problem with the product itself.

Ms. FELDT. No, and I was going to continue on, thank you.

But Kingston was the catastrophic failure due to the stability of the dam.

But we also have damage cases that talk about arsenic and mercury and selenium migration to groundwater and to surface water that potentially affect drinking water sources. And all those damage cases are identified in the rule itself.

So, in 2000, we did not have that information. We continued to gather that information. Between 2000 and now, Kingston also happened, so we have looked at all the additional information that we have to support either a D or a C option. But, in May 2000, we

did determine that it was—regulation under D was appropriate as a solid waste.

Mr. LUETKEMEYER. So, basically, you are saying that the problem is impoundment; it is not the product itself, because, look, if you have, we got a situation in my home State where we had a large water reservoir on top of a mountain. The reservoir broke. All the water ran down the mountain, flooded the stream. There was a massive flood. It washed everything along the way. That is a catastrophic event, as well. That was due to water. You can have this with anything. You can put salt into an impound area and have a dam break and go done the stream. That will destroy the area as well. I think it is an impoundment problem here that is the problem. You haven't told me yet where the problem is with the product.

Ms. FELDT. The problem with the product, and again, the damage cases that we have that we can submit for the record talk about leaching of the contaminants that are in the coal—

Mr. LUETKEMEYER. We are leaching, those are from an impoundment area.

Ms. FELDT. That are unlined, that are not lined, that do not have—many of them do not have liners—some of them do—that are not lined, that we have damage cases that show that those contaminants, arsenic, mercury, selenium, leach into the groundwater from these unlined units.

Mr. LUETKEMEYER. Again, it is an impoundment problem.

Ms. FELDT. It is an impoundment and landfill. And what we are proposing in the C or D proposal is to regulate the impoundments or landfills that, in many cases, are unlined.

Mr. LUETKEMEYER. So what we have identified then is that there is an impoundment problem that we are trying to work with here. We need to find a way to make sure that we contain what is there. The product as it is used now in all the other uses you have not found a problem with that?

Ms. FELDT. Right. What we are regulating—

Mr. LUETKEMEYER. You said yes?

Ms. FELDT. Yes—is the disposal and management from the impoundments and landfills themselves, which result—has resulted in catastrophic failures, in some instances, in migration of contaminants to groundwater and surface water. So that is what we are proposing to regulate under the D or C; not the safe and environmentally sound beneficial use of coal combustion residuals.

Mr. LUETKEMEYER. So what we need to focus on here is, how do we dispose of it once it is sitting in an impound area, is that correct?

Ms. FELDT. Yes.

Once it is in the impound area, it is considered disposal. In the impoundment or the landfill itself, that is disposed coal combustion residuals.

Mr. LUETKEMEYER. But at this point, you haven't found a problem with its use in concrete or any other uses of the ash itself?

Ms. FELDT. No, not at this point.

In fact, what we call capsulated, encapsulated uses, and we again talk about this in the rule, those products are exempt from this rulemaking effort.

We are not proposing to regulate those under C or D. And we believe that fly ash and concrete, wallboard, et cetera, those are all considered capsulated uses and should continue. And the administration and Administrator Jackson supports the continued beneficial reuse of those products, and they would not be regulated under either the C or D option.

Mr. LUETKEMEYER. I think that is a key point of the hearing here as well, because I think we want to make sure that we don't describe this as a hazardous material that has been found and used for over 50 years. In my testimony here, we had one example back in 1953, and we haven't had any negative impact from the usage of this material at this point. And there are other uses being developed as we speak.

So as long as it is used, the product is encapsulated, as you say, we don't have a problem.

The problem is with the impoundment of it and how it is stored, and therefore, it can, if it is not stored correctly be a problem. That is where we need to focus. Is that the gist of your testimony there?

Ms. FELDT. Yes, that is correct.

Mr. LUETKEMEYER. One of the things that is concerning me also is during your determination of the costs of it, by raising, by looking at the impact of what your rules may do to the costs, say that the costs incurred by electricity generators would succeed in passing on all those costs to the customers, and therefore, its impact would be insignificant.

That to me is a very laissez-faire approach to what is obviously a huge impact to the customers. It is just another way of putting more cost burden on the individuals and businesses who utilize, and everybody does, electricity.

So I am a little, I guess, frustrated by the fact that the cost was looked at, and you say, well, because it is going to be passed on, it is not going to be significant. I am a little miffed at how they can come up with that as not being significant.

Ms. FELDT. Let me, we have developed costs for each of the options in terms of costs and the benefits. We did do in our regulatory impact analysis for the proposed rule, we factored in that the national electricity prices averaged 8.84 cents per kilowatt hour.

Assuming that 100 percent of the cost of the proposed rule would be passed on to the electric consumers, the regulatory impact analysis estimated that the average nationwide increase would be approximately .8 percent with local markets increasing anywhere from zero to 6 percent. And we can provide more information.

But that was assuming that 100 percent would be passed on to the customers, and we, that was the analysis that we had, and we can provide more information.

Mr. LUETKEMEYER. So you are going to raise somebody's electric bill 6 percent? Is that what you just said?

Ms. FELDT. No. We did the analysis. That is the analysis. Again, we have not made a decision on either C or D in terms of the proposal. We are still evaluating all options.

Mr. LUETKEMEYER. But you said it is going to raise the individual 6 percent?

Ms. FELDT. We are required as part of the rulemaking to do a regulatory impact analysis on the cost, and that was part of our

analysis that we looked on. And I am not making a statement that we are raising the consumer rates by 6 percent. That was the bounding case of our analysis.

Mr. LUETKEMEYER. But you don't think that is significant?

Ms. FELDT. I am not, I am not prepared to say whether it is significant or insignificant. That was the bounding cost of our analysis.

Mr. LUETKEMEYER. We have a lot of customers in here, I am sure, that think that would be pretty significant to raise it 6 percent. And I think there would be a lot of business folks—we are a small businesses committee—if their utility bill were raised 6 percent, that would be pretty significant. I have a family in my district that if it raised 6 percent, they are out of business, quite frankly.

Ms. FELDT. Again, we have not made a decision the C or D, and that was the bounding scenario that we looked at and are required to look at in our regulatory impact analysis, but we welcome any comment on that.

Mr. LUETKEMEYER. Thank you, Mr. Chairman. I will stop right there.

Chairman SHULER. I would like to thank the ranking member.

At this time, I will yield to Mr. Bright from Alabama.

Mr. BRIGHT. Thank you, Mr. Chairman.

Ms. Feldt, thank you for your testimony today. As I said earlier, and that does concern me, a 6 percent increase. That could be a significant factor for some of the small businesses in my community. And I would like to get more information about that as you obtain it if you could supplement your statement here.

Ms. FELDT. Sure.

Mr. BRIGHT. The other factor, and I think the chairman and ranking member pretty much covered most of my concerns here but one, and that is, EPA has a real, very difficult balancing act here to protect the public, protect our environment, and also at the same time understand what affect you may have on the businesses out there who will be affected. And that is a major concern, and I appreciate that balancing act that you have to conduct every day.

However, with that said, did EPA consider the potential affect and possibly negative affect it would have on the industry by designating CCB as a hazardous material?

Ms. FELDT. We heard from many of the groups that you will be hearing from later on as well as different industry representatives and communities that we met with on the stigma of that designation.

Mr. BRIGHT. You heard from them, but did you make a study or have they conducted a study of some type to see definitely what affect it would have on the industry out there?

Ms. FELDT. We do not have any specific information that suggests—our position, as I stated in my testimony, is that beneficial use will actually increase with the designation under either C or D because of the economics.

So we did not have any information that supports the stigma argument. We request in the proposal itself, request for comments on information and data that supports the stigma, and clearly, we will evaluate that as we make your final decision.

Mr. BRIGHT. Was there any study done or evaluation or assessment done by EPA on the encapsulated use of CCBs, in other words, even though you have clearly stated here today, and I am somewhat intrigued with your statement, you have no intention or this regulation has no intention of regulating useful or beneficial use of CCBs, is there any study out there that you know of or are aware of that there is a hazard to the public, to the general public, of encapsulated CCBs and beneficial use?

Ms. FELDT. From what we have seen to date, encapsulated beneficial use, we have not seen any impact to the environment from that.

We did receive a lot of input and comments, and we are requesting comments. We have stated that we believe capsulated beneficial use is completely protective of the environment, but we are seeking comment on all beneficial use, and specifically unencapsulated use, which in many cases also are very legitimate beneficial reuse and safe for the environment. But we are seeking comment in the proposal.

Mr. BRIGHT. So would it be fair to say that you are continuing an ongoing assessment or study of potential hazardous use of encapsulated CCBs? Is that fair?

Ms. FELDT. None of the analysis that we have done to date has shown any environmental harm from encapsulated use. If we get comment and data during this process from the full set of the public that is engaged on this, we will clearly evaluate that.

Mr. BRIGHT. Thank you very much for your testimony.

And Mr. Chairman, I will yield back the remainder of my time.

Chairman SHULER. I thank the gentleman.

I want to recognize Mr. Thompson from Pennsylvania for his 5 minutes for questions.

Mr. THOMPSON. Thank you, Mr. Chairman, Ranking Member, I appreciate this hearing.

Thank you, Ms. Feldt, for your testimony.

Two clarifications and then a possible solution I want to throw out there and get your opinion on, change gears a little bit. But the first clarification is from my last two colleagues that talked, you talked about electricity cost analysis and that your analysis up to this point has 6 percent, potential 6 percent rate increase.

Did that analysis also include the other realities that maybe aren't in place right now, but I think are, frankly, I think are threatening to drive up the cost, the cap-and-trade, some of the other related and unrelated EPA regulatory initiatives that are kind of outside of—that are occurring administratively that would push up the cost of fossil fuels? Deregulation in States like Pennsylvania, which right now, we are seeing a—I think we are going to see a huge jump in electricity costs. It is not in place now, but it would be at the time of whatever implementation as you make a decision. Or just the energy mix, I mean, States like Pennsylvania, we are blessed with over 60 percent of our electricity comes from coal, which is the most affordable and reliable. Were any of those factors which are—that last one is just a characteristic of Pennsylvania, but the other three, that are not in place now, but frankly, there is a real threat—I consider it a threat—will be in

place at the time that the EPA would implement this; was that considered in this cost analysis?

Ms. FELDT. I will need to get back to you and submit that information for the record.

I believe that these costs reflect the impact of our rule. But I will need to double check that and get back to the record for that.

Mr. THOMPSON. Because those things are looming there.

The other thing is, even if it is just 6 percent—and I would argue it is probably going to be much higher given what I just described of things that I think are, unfortunately, a looming threat to cost of electricity, especially in States like Pennsylvania, which we rely on coal, we value it—wouldn't this, the byproducts that we are talking about today, the subject of this, when they are able to sell those for very qualified, wonderful uses to be able to take that fly ash and use it to build things, or to use it in different ways, that has got to drive up the cost of those. Those generators of electricity, who will produce that byproduct, they are going to absorb these new costs; any business model would tell you that if their costs go up, they have to raise the cost of what they sell these byproducts for. Would you agree with that?

Ms. FELDT. I am not prepared to agree or disagree with that. I think what—we did not in this proposal regulate the beneficial use.

Clearly, our analysis shows that we don't have any information that supports a stigma argument for beneficial use, but we have requested comment, information and data to support that argument, and clearly we will evaluate that in our final analysis and decision.

Mr. THOMPSON. Great. I think it is a reality, so I hope those who are, obviously, in that business, who would have those business models, would come forth with that type. I think it would be helpful for you to have that.

I promised you a potential solution. You had acknowledged earlier that what we have is an impoundment issue, and so I just want to throw this out there and get your opinion on this. As I have looked at this, one of the things I have seen out there are things that deal with geosynthetics as a class of product that provides solutions for safe storage of coal combustion residuals until they are reused. And geosynthetic materials include liners, such as geomembranes, geosynthetic clay liners, structural reinforcement using geotextiles, geo grids, drainage applications using geo composite drains. Safety concerns regarding coal combustion residuals can be mitigated if storage sites are lined and the leach agent is prevented from entering the environment. You talked about that when we acknowledged that this was an impoundment issue. The geo composite draining systems draw the water out of the coal combustion residual slurry in the surface impoundment, rendering the material into a more solid and stable state.

Now applying these geosynthetic solutions to the storage of coal combustion residuals, keeping them in a safe secure state until the materials can be recycled in the production of cement, wallboard, all the structural road base, all the things we have talked about that has been mentioned and many more, so since the future of coal combustion residual beneficial use industries and their employees are dependent upon safe secure handling and storage of material and since the geosynthetics provide for safe secure stor-

age, do you support congressional action to direct the use of these geosynthetic systems or through action by the EPA to encourage use of these materials in regards to containment?

Ms. FELDT. I certainly appreciate your suggestion, and under either proposal, again, the impoundments that we are regulating are impoundments that are used for disposable, not beneficial use. And we are proposing geoliners in either proposal. So I appreciate your comments. And that is how I will answer your question.

Mr. THOMPSON. I appreciate it. And I look forward to you getting back to me in terms of those other factors—

Ms. FELDT. Will do.

Mr. THOMPSON. Regarding electricity analysis.

Ms. FELDT. Will do. Thank you.

Chairman SHULER. I thank the gentleman.

At this point in time I would like to recognize the gentlewoman from Pennsylvania, another Pennsylvanian here, Kathy Dahlkemper for 5 minutes.

Mrs. DAHLKEMPER. Thank you Mr. Chairman.

Many of the questions and concerns that I had wanted to bring up have already been addressed.

But I just have one question for you, Ms. Feldt. Would it make sense for Congress to give the EPA the authority to regulate under Subtitle D and create new disposal national standards that can be enforced at the same time avoiding that stigma of hazardous or special waste?

Ms. FELDT. We have currently proposed two options in our rulemaking effort, and we are considering both options. Clearly, we would provide any technical support necessary, but we have not decided on any, either of those options right now.

Mrs. DAHLKEMPER. So, at this point, just waiting for comment through the rules process?

Ms. FELDT. Correct.

Mrs. DAHLKEMPER. As I mentioned, Mr. Chairman, most of my questions have been addressed.

Obviously, we are all very concerned about, my colleague from Pennsylvania has already mentioned the increased cost that Pennsylvanians are going to be incurring in utilities, and obviously, we are all very concerned about that for our businesses, for our individuals, and I certainly hope that you—I would also be interested in some of the information on how that came about. So I would appreciate if you could pass that on to me.

Ms. FELDT. We will make sure to submit that for the record.

Mrs. DAHLKEMPER. Thank you very much, Mr. Chairman.

I have to yield back. I have to get to a markup in another committee so thank you.

Chairman SHULER. Thank you.

For the record, when you say you are getting back to us, can we get that back in 7 business days?

Ms. FELDT. We will be glad to provide that.

Chairman SHULER. Thank you.

Any other member have any other questions they would like to?

I just had a couple more that I would like to state. EPA says that if it is under Subtitle C regulations, that it will encourage recycling of coal ash? I don't understand how it is going to encourage recy-

cling. I know EPA says it is because the disposal is going to be more expensive, so it is going to encourage people. But if it is put under C, then it is going to be looked at as a hazardous waste. And I just don't understand how more people are going to recycle it if it is listed under C, just because the disposal cost is going to increase from up to zero to 6 percent increase.

Ms. FELDT. We are requesting comment on the stigma argument and the real data as I indicated before. In the preamble to the proposal, EPA lists several examples which illustrate that hazardous waste or other materials subject to RCRA Subtitle C are used and recycled. These examples suggest that hazardous waste label does not impose a significant barrier to beneficial use. They include things like electric arc furnace dust, which is a listed hazardous waste; electroplating wastewater sludge, which is a listed hazardous waste; used oil that is regulated under RCRA Subtitle C standards. So we have actually seen the reverse trend to the stigma argument.

But, again, we are asking for data and information from all the stakeholders and the industries to comment on the stigma argument. But we have seen in other cases the reverse, where recycling rates have actually increased because of the increased disposal cost and the economic aspect of that.

Chairman SHULER. Well, thank you.

And I want to thank the EPA and the staff for the work that they have done on this. I think there is still a lot of work to be done. And I think, as always, a compromise is much, much better.

And for the recyclers, those people who are lowering the emissions, making better use of a product, making sure that, if we can utilize it in areas, that we don't have to stack it on top of one another like happened in Kingston, Tennessee, that we can make a better use of that and utilization of the fly ash that will give us an opportunity for small businesses to continue to grow and not restrict those jobs. But I think we really got to come to a compromise.

And I think, from this entire panel, and this is a very unusual—but the way Congress should be working and in a very bipartisan way. I mean, I think you have seen across the board here that we are in agreement that putting it in under Subtitle C may create, which has been indicated to us through multiple letters that we have received that says that the impact, the stigma under Subtitle C would have a devastating impact to small businesses.

So we are really hoping that we can bring this back to the middle. We certainly all agree, I think, amongst us that the disposal part is the real issue here, where it is being disposed onsite, and having the geosynthetics and making sure that we can have a proper way to monitor and to regulate that in those site areas is the real issue.

And sometimes in Washington, we get all caught up in things, and we forget about the small businesses. But this committee never forgets about small businesses. And it is across the board that we want to make sure that they are taken care of and it doesn't have such a huge impact on them, because some of them are mom-and-pop operations that have been in business for a very long time, conducted themselves in the appropriate manner, and look at the posi-

tive things that we are gaining from it, lowering our carbon footprint, lowering emissions.

So, I will really want us to be able to work together, and I am hoping that through this committee and the others with jurisdiction, that we can have some good dialogue with the EPA and, obviously, the input from the community. And I know that that is what you are waiting for.

And for the record, it is kind of a housekeeping, for the record, someone will be staying from the EPA to listen to our next panel, because that is real important. That is one of the most important things to be able to listen. They are our constituents. They are our people. And so we want to make sure you can hear them well.

Ms. FELDT. I appreciate it. Unfortunately, I personally can't stay, as I have another meeting with the administrator, but I do have Amy Hayden, through our Office of Congressional and Intergovernmental Affairs; and Randy Deitz, who is our senior adviser to our office and the Office of Solid Waste and Emergency Response. They will be staying on to hear and welcome any input, both at this hearing and throughout the public comment process, on all aspects, including the impact to small business.

We definitely want to hear and consider all those factors, as I indicated in my testimony.

Chairman SHULER. I want to thank you for your time and your commitment to this. And I truly feel that there is a solution, that we can come to a great compromise and get this thing resolved and worked out in a way that everyone wins. And that is what we try to—not everyone can win always, but we try to. I think in this situation, we can all win on this.

So thank you so much and thank you for your testimony.

And at this time, we will have the second panel come forward.

Ms. FELDT. Thank you so much.

Chairman SHULER. I certainly want to thank the next panel, obviously, for your commitment to be here, but also for your industries and what you mean to small businesses throughout this country.

Obviously, we have heard from the EPA, and now we get an opportunity to hear from you. Just one thing, let's try to stay under that 5-minute mark. Read your testimonies as fast as you possibly can, because we are going to have votes in about 30 minutes, and that could last a long time. So we are going to try to get through this as quickly as we possibly can and ask questions as fast as we can as well.

Chairman SHULER. So, without further ado, our next witness is Dr. Craig Benson. Dr. Benson is the co-director of the Recycled Materials Resource Center in the University of Wisconsin-Madison. The center serves as a research and outreach facility for the beneficial use of recycled materials.

Mr. Benson you will be recognized for 5 minutes.

STATEMENT OF CRAIG H. BENSON, PH.D., PE, DGE

Mr. BENSON. Thank you, Mr. Chairman.

I am glad to be invited here to provide my input and my experience to your committee. I want to make a few points from my testimony that I think are particularly important.

The first one is that the safe and wise beneficial use of coal combustion products is truly good for our environment. We create more durable and longer-lasting infrastructure. As a result, we don't need to repair and replace things nearly as often. We really gain some significant benefits as a result.

Just some calculations we have done, in terms of energy usage, savings on the order of 1.7 billion households of energy usage each year; 31 percent of the water use in California equivalent; equivalent greenhouse gas reduction of nearly 2 million cars. These are really substantial beneficial impacts or beneficial attributes that we get from using these materials in sustainable construction.

And I would argue that, given the pressing energy and climate issues that we are talking about today, that we ought to walk carefully when we make decisions about how we might affect that.

The second point I would like to make is that we have been looking at this issue for nearly two decades of whether these materials are hazardous. And the materials that we are looking at today really are not different than the ones we have considered in the past to be nonhazardous. There really hasn't been a substantial change in those materials. There is really not a scientific reason to designate these materials as hazardous.

The third point, and one of the issues of concern, is that the release of trace elements and other constituents from coal combustion products used in reuse applications—things like arsenic and cadmium were mentioned earlier—the thing that we need to realize is that all materials that we use in the environment release these things. And really what it gets down to is really safe and wise use of materials and engineering things properly so that we can manage those releases to the environment in a way that protects the public.

We know when we use CCBs in a concrete like application that those releases are essentially negligible; that it is a very safe and wise use. Our history has shown that over time and time again.

The fourth point, and I think this is a particularly important one, is that in the 20 years I have been working in this industry, interacting with people who use industrial byproducts in construction projects—people who actually put it into their infrastructure, who buy these products and assume responsibility for it being in the infrastructure. People like State highway departments, counties, public works directors, the people who buy that. And one of the key issues that we deal with in promoting the beneficial use of industrial byproducts is overcoming issues of perceived risk. People are concerned about the risk of using that product. And I would argue that the designation of these materials as a hazardous waste, even with an exemption for beneficial use, will have a very significant impact on that perceived risk and will result in a significant reduction in the use of these materials and construction.

I would argue as well that it is not only these materials that will be affected by that, but all the industrial byproducts that we use will be affected adversely. One argument could be made if it is coal combustion products this year, what will it be next year? What is the use that I am going to be concerned about? That perceived risk is very real. The stigma associated with the hazardous waste des-

ignation is very real. And I consider that a major issue that we need to consider.

I would argue as well that we actually know how to manage these materials in a very safe and wise way, both in the beneficial use application and in the disposal application. In my home State of Wisconsin, we have been doing this for 20 years. We don't have environmental problems with our disposal facilities or with our reuse applications. Rules like we have in Wisconsin can be applied nationwide. They can be regulated at either the State or Federal level, and they can very effective. And I would argue that that type of example could be used to create some type of national rule or policy.

So I will leave it at that point. Thank you.

[The statement of Mr. Benson is included in the appendix.]

Chairman SHULER. Thank you, Dr. Benson, for your testimony.

Our next witness is Thomas Adams.

Mr. Adams is executive director of the American Coal Ash Association located in Aurora, Colorado. The association is devoted to recycling materials created when coal is burned and generates electricity.

Mr. Adams, you will be recognized for 5 minutes.

STATEMENT OF THOMAS ADAMS

Mr. ADAMS. Thank you, Mr. Chairman.

We appreciate the opportunity to come speak to you and the subcommittee today about this environmental success story that is under some threat right now.

Our association has a diversity of membership in very large utilities to very small businesses. Many of our members, a great number of them, are small businesses that include entrepreneurs that are bringing marketing and technical and contracting services to the market and also bringing innovation to the market that will increase the beneficial use of coal combustion products and expand them so that we are using more recycled materials and less virgin material contributing to sustainability.

Our production and use survey is conducted annually. For the last survey in year 2008, we determined 136 million tons of CCP weregenerated, which is the second largest waste stream in the country. Of that 136 million tons, 44 percent, or 60 million tons, were recycled. Only 10 years ago, that recycling rate was 30 percent. So, in 10 years, we have increased our recycling almost 50 percent, not in small measure, including support from the EPA under its Coal Combustion Products Partnership, C2P2.

It is curious to hear EPA testify that they support recycling, yet they have taken this program, which has gone a long way to expanding recycling, and suspended it and pulled down its Web site. So if EPA does in fact support recycling, they shouldn't be taking unilateral actions like that that deprive people of information on how to safely recycle.

We want to keep to the time limits here and get right to the point. The stigma is real. We are seeing the effects in the marketplace of the shadow of regulation already starting to cause people to turn away from using these materials that are considered to be beneficial, even by EPA.

When we take a look at the marketplace and we see that consumers have a choice between using a material which may be considered hazardous for some reason or choosing another product which doesn't have that stain or that stigma, the rational choice is to use the nonhazardous product. And that is where this stigma concern is coming from.

So we know the stigma is real. The effects are not only from the use by specifying agencies, and you are going to hear from some of them very shortly, but also there are local governments and State governments that have prohibitions from using these materials beneficially if they are considered to be hazardous for any reason. Professional liability insurance may not be available for those designers who include these materials in their projects. And our small businesses are very concerned that venture capital is going to dry up, that the folks that provide that venture capital are not going to be willing to put their money into a product or a service that has a potential hazardous waste label stuck on it.

In an effort to address these disposal problems, and we all know that there is a disposal problem, as indicated here in testimony today, the EPA has created a potential through that Subtitle C proposal to cripple, if not destroy, an industry that is heavily populated with small business which provide a substantial environmental and economic benefit to society. We do know that there is a better way, and we would like to suggest to you to the better way is for Congress to provide Subtitle D national enforcement authority to EPA.

EPA itself has said publicly that Subtitle D rules are appropriate, and now we would like to see them have that tool so that we can get to that middle ground you talked about you talked about, Mr. Chairman, where we can compromise, protect human health, the environment and continue to promote recycling. Thank you.

[The statement of Mr. Adams is included in the appendix.]

Chairman SHULER. Thank you, Mr. Adams.

Our next witness is Lisa Cooper, who is the senior vice president and general counsel of PMI Ash Technologies, headquartered in the great State of North Carolina, in Cary, North Carolina.

You will be recognized for 5 minutes.

STATEMENT OF LISA COOPER

Ms. COOPER. Thank you, Chairman Shuler, Ranking Member Luetkemeyer and distinguished members of the committee. I sit before you as the owner of a small business, a small business who focuses entirely on coal ash recycling and concrete.

Although we appreciate the lengths EPA has gone to in using the words ″special waste″ instead of ″hazardous waste,″ a Subtitle D option would be devastating to our small business and our competitors. EPA isn't listening. Despite repeated attempts to educate them by standard setting organizations and us, Lisa Feldt just testified that she didn't have enough information.

I read to you from a prepublication letter from ASTM, dated December 22, 2009: A hazardous waste designation, even with an exclusion for beneficial use, would cause the ASTM standard for fly ash to be removed from project specifications, due to concerns over

legal exposure, product liability and public perception. This will likely result in little or no fly ash being used beneficially in concrete or other applications that support sustainable objectives.

No one, Chairman Shuler, is going to put concrete in their son Johnny's room with a hazardous waste in it. No one is going to want it in a hospital with their mother there.

I met with EPA prior to the publication. I was honored to meet with them. They are not listening.

Subtitle C won't work. It will drive good-paying green jobs offshore, mine and my competitors and many other innovative small businesses. We won't seize the opportunity to create thousands more green jobs, either, an opportunity for shovel-ready projects today.

We are for increased regulation of coal ash under Subtitle D. We are for EPA having direct enforcement authority under Subtitle D. And I would note, I am just really saddened that EPA didn't answer that question, whether they wanted Subtitle D authority. Because we actually asked them, why don't you partner with us, so you have a level playing field, so you can adequately look at Subtitle D with direct enforcement authority as well as Subtitle C with direct enforcement authority.

We need Congress to quickly pass a bill to give EPA direct enforcement authority. Jobs in our sector and deals are no longer out there. Everyone is in a wait-and-see mode.

The NGOs say there is a line in the sand. They won't talk with us because they want Subtitle C for disposal. They are willing to sacrifice our small business recycling industry to get Subtitle C.

There is a lack of trust. We are caught in the middle, no one willing to listen. Our small businesses and our employees will not be able to survive these typical struggles in D.C.

You need to break this logjam. Please work on a bill that provides Subtitle D regulations for coal ash but also provides direct enforcement authority, similar to municipal solid waste. This will create good-paying jobs.

We create 180 temporary jobs in building our types of capital-intensive facilities and 44 permanent jobs. Our technology requires regulatory certainty. They are long-term deals. We don't even use venture banks; we use real banks. Banks, utilities, ash marketers, ready-mixed customers, all need to know that fly ash recycling and concrete is and will be okay and won't be stigmatized by a hazardous waste designation.

CO2 savings are real. We are one of the few companies that have certified and verified CO2 credits, not through a voluntary scheme, but through the State of Massachusetts. It is very unfair for me as a small business sitting here hearing that EPA counted the CO2 benefits that our industry works for but didn't count the cost to us. Don't let regulatory overreaching get this wrong. Small businesses such as ours need you to stand up for us and take a stance. Thank you.

[The statement of Ms. Cooper is included in the appendix.]

Chairman SHULER. Thank you Ms. Cooper.

Our next witness is Mr. Richard Stehly. Mr. Stehly is a principal of American Engineering Testing Incorporation, located in St. Paul, Minnesota. And American Engineering Testing is an employee-

owned corporation providing geotechnology and environmental consulting and testing services.

Mr. Stehly, you will be recognized for 5 minutes.

STATEMENT OF RICHARD STEHLY, PE

Mr. STEHLY. Thank you, Mr. Chairman, and distinguished members of the subcommittee. Thank you for taking up this issue. I believe it is very, very important. And thank you for inviting me to give testimony.

As you noted, I am a principal and founder of American Engineering Testing. In December 1989, it was a small business; it was 14 people. But we have had success, and it has grown to about 250 people.

I am also an active member in the American Concrete Institute, and I am its president this year. The institute is 106 years old, and it is the world's knowledge center on concrete. We have 20,000 members, many of them small businesses, designers, ready mixed suppliers, material suppliers, laboratories. They are all interested in this issue. We have more than 100 chapters, a third of them outside the U.S.

For a standards developing organization, we are probably best known for our document the committee 318 generates. This is the Building Code Requirements For Structural Concrete. That code is then adopted by the International Code Council in the International Building Code. States then adopt the code as their building code. These are the minimums that are required for building structures with concrete.

Code is translated into Spanish as an official version. It is used throughout Central America and South America. It is also translated into Arabic, Chinese. The Iranians translate it into Farsi. It is Korean and Portuguese. It is used worldwide. I visited Vietnam in April. We are about to sign a memorandum of understanding with Vietnam that will allow them to use the code for their structural concrete code.

The code contains references to using fly ash in making concrete. Concrete is very useful in making—fly ash is very useful in making concrete. It makes it stronger and last longer. It can make it easier to place and reduces cost.

Portland cement is the primary binder in concrete. It is energy intensive to make; about 5 million BTU to make a ton. It releases about a ton of CO2 when you make it.

When we use fly ash there is pretty much a direct substitution. You use a ton of fly ash; you use a ton less of cement. Now, you will remember in December, in Denmark, at the UN Climate Summit, the President made a pledge to reduce CO2 emissions, 2020, 17 percent over 2005 emission level. Currently the industry is about 40 percent below that target. It is because of the reduction in volume because of the economy. But going forward, construction will recover, and by using fly ash, we could stay under that target every year, including 2020.

I provided you information from the U.S. Geologic Survey on cement use. They have been keeping information since about 1900. If you look, cement use peaked in 2005 at about 128 million tons. We produced about 100. We imported about 30. Currently, we are

40 percent under that peak, but as it recovers, as the economy recovers, construction recovers, it will grow. You can reduce the need to import cement by using fly ash.

Lastly, there are no technical barriers to using more fly ash in concrete. The knowledge is there. It is in our documents. Fly ash is discussed in more than 100 of our technical documents.

The barrier is acceptance. I have included in my written testimony an article by Nadine Post from the Engineering-News Record. Now, she had the courage to write in April what is on a concrete users' minds. She wants to know, is fly ash the next asbestos?

I have seen no reply from the EPA. Managing supply ash's image is key to increasing acceptance. Now, as we know, EPA is considering a Subtitle C type of designation for its regulation. We think, if that should happen, use will decline. The many different audiences that have to assent to its use will consider it, and they will choose not to use it. These will be the generators. These would be the ready-mixed suppliers. These would be the engineers of record for the buildings. These would be the contractors. They will look at it, and they will turn away.

Lastly, we are going to survey our industry. We are going to determine the impact of stigma. We will have those results available. We will provide them to EPA. We will provide them to you if you wish and OMB. Thank you.

[The statement of Mr. Stehly is included in the appendix.]

Chairman SHULER. Thank you, Mr. Stehly.

Our next witness is William Gehrmann. Mr. Gehrmann is the president of Headwaters Resources Incorporated in South Jordan, Utah. Headwaters Resources is a marketer of coal ash combustion products.

Mr. Gehrmann, you will be recognized for 5 minutes.

STATEMENT OF WILLIAM H. GEHRMANN

Mr. GEHRMANN. Thank you, Mr. Chairman, honorable members of the committee.

Our company is the Nation's largest marketer of coal combustion byproducts in the country, with operations on over 100 power plant sites.

As a manager and marketer of coal ash, Headwaters touches every link in this chain of activity that makes beneficial use of the material possible. Small businesses comprise a significant portion of many of the links in this chain.

As other witnesses at this hearing will testify, using coal ash instead of disposing it creates significant benefits for the environment and users of the material. The environment benefits by conserving natural resources and constructing fewer landfills. Use of coal ash to replace cement also results in millions of tons of greenhouse gas emission reduction.

Coal ash users benefit by being able to make products that are stronger and more durable than products made without coal ash. Coal ash also has properties that help engineers solve specific problems, such as the presence of reactive aggregates in concrete.

But just because the benefits of using coal ash are great does not mean it is easy to get people to use it. Significant investments

must be made to be able to transport and deliver materials to users so that it is available when they need it. Users must be educated on how to properly use the materials, the benefits of the materials, and how to properly handle them.

Additionally, it is important to remember that coal ash users have alternatives to using coal ash and can choose to eliminate its use.

In my written testimony, I describe several levels of the coal ash beneficial use industry and explain how each level must respond to a hazardous-when-disposed designation for coal ash. These levels include ash producers; utilities that generate it; ash marketers, like Headwaters; ash technology developers and providers, like PMI Ash Technologies; product specifiers; ash users; and end users. All these parties will find it more difficult to use coal ash if it is designated hazardous for disposal.

If any of these levels decided that using coal ash was a bad idea, then the beneficial use of coal ash would significantly decrease. As I describe in my written testimony, all of these levels would face major challenges if coal ash were designated as a hazardous waste for disposal.

Some of the participants in the coal ash chain will worry about their health and safety if coal ash is labeled hazardous. Other participants will worry about being sued by people who are worried about their health and safety if coal ash is labeled hazardous. Most participants will have to deal with a host of unanswered questions relating to how they will have to change their handling of the material if coal ash is labeled hazardous.

The damage from this proposal is already being felt. In proposing a hazardous-when-disposed regulatory framework for coal ash, the U.S. EPA has already created a new barrier to increasing the beneficial use of coal ash. End users exposed to a barrage of negative news articles about coal ash have already begun calling our concrete producer customers asking if the concrete they are using contains a dangerous material.

Some product specifiers, such as the Los Angeles Unified School District, have already removed coal ash from their concrete specifications as a direct result of the EPA's proposal.

We are seeing an increase in requests to amend indemnification language in supply and purchase agreements, pushing any potential liabilities and risks all the way down the coal ash supply chain. Many small businesses along the supply chain will be forced to make difficult decisions regarding the continued use of coal ash in their products. Many of these businesses were built around the beneficial use of coal ash.

In meetings with me and other representatives of the coal ash industry, EPA officials have indicated they support the beneficial use of ash, but actions speak louder than words. And EPA has done precious little to demonstrate support for legitimate coal ash use.

To the contrary, EPAhas unilaterally and without explanation removed its Coal Combustion Products Partnership information from its Web site. End users seeking information from the EPA about coal ash are now greeted with a single statement that Coal Combustion Products Partnership program Web pages have been removed while the program is being reevaluated.

The irony of this is also unnecessary. The actual engineering standards for disposal facilities are essentially the same under the EPA's two proposals. The EPA's hazardous proposal appears calculated primarily to get Federal enforcement authority over the regulatory program. EPA appears to be willing to sacrifice a substantial and beneficial industry merely to obtain greater regulatory influence.

EPA should do what is right for the environment, not what is best for the EPA's authority. The best course of action for our Nation's environment is one that encourages safe and beneficial coal ash used as a preferred alternative to disposal. Whatever material remains unused can then be disposed in a safe and effective manner.

The hazardous-when-disposed approach proposed by the EPA will have exactly the opposite effect, reducing coal ash use activities and therefore creating more waste that will be landfilled.

Thank you for the invitation to testify and for your interest in this important topic.

[The statement of Mr. Gehrmann is included in the appendix.]

Chairman SHULER. Thank you, Mr. Gehrmann.

Our next witness is Robert Garbini. Mr. Garbini is the president of the National Ready Mixed Concrete Association.

You will be recognized for 5 minutes.

STATEMENT OF ROBERT GARBINI, PE

Mr. GARBINI. Thank you, Chairman Shuler, Ranking Member, Mr. Bright and Mrs. Dahlkemper, thank you for the invitation to testify on behalf of the National Ready Mixed Concrete Association.

As a matter of scale, ready-mixed concrete consumes 75 percent of all the portland cement used in this country. We also represent 1,500 concrete manufacturers in 50 of the State-affiliated organizations. Approximately 85 percent of NRMC'smembers are small businesses.

Concrete is the most widely used construction material in the world. It is produced and consumed in every part of this country. In fact, no construction takes place without some kind of concrete products in it.

. Based on NRMC's latest industry data survey, we estimate the U.S. ready-mixed concrete industry exceeded $25 billion in 2009, with over 130,000 people directly deriving their livelihood from the industry.

With regard to the proposed rule, the ready-mixed concrete industry is the largest user, beneficial user, of fly ash. In 2008 alone, which was a down year, the industry used 15.8 million tons of fly ash in the manufacturing of ready-mixed concrete, making fly ash by far the most widely used supplemental cementitious material. A 1998 survey of ready-mixed concrete producers showed that over 55 percent of all the ready-mixed concrete contained fly ash at an average of 20 percent by weight of total cementitious materials. It is probably higher at this point, certainly higher.

Fly ash is used in combination with portland cement to impart beneficial qualities to concrete. The environmental benefits of using industrial byproducts in concrete results in longer-lasting structures and reductions in waste materials sent to landfills, raw mate-

rials extracted, energy required for production and air emissions, including CO2.

There are also economic benefits using fly ash in concrete. Fly ash is significantly less expensive than portland cement and, therefore, reduces the material cost of concrete while providing enhanced benefits and performance.

Also, the concrete industry, while it uses significant fly ash, it is estimated that there still remains about 42 million tons of fly ash that our landfilled annually. Although not all fly ash is of significant quality for use in concrete, it is still estimated that the concrete industry could increase its current use to above 30 million tons per year by 2020, which would reduce the concrete industry's carbon footprint by 20 percent.

Based on the ready-mixed concrete industry's extensive use of and reliance on fly ash in concrete and after examining EPA's proposed rule, we have determined that the RCRA Subtitle C as a hazardous designation for fly ash will lead to these following unintended consequences for small businesses in our industry: Number one, an increase in production costs; number two, an increase in the liability for concrete producers, as you have heard also from some of the previous speakers; number three, the stigma for the use of fly ash in concrete; the potential elimination of fly ash in concrete and a dramatic impact on the Nation's infrastructure.

I would also add that we are still evaluating whether or not we would even want to see the designation of EPA's control under a Subtitle D. We are still not quite—we intend to do a survey, which we should have back in the next 3 months. We have asked EPA for a 120-day extension. We are waiting for the response back from that.

Mr. Chairman, members of the subcommittee, thank you for hearing my concerns.

[The statement of Mr. Garbini is included in the appendix.]

Chairman SHULER. Thank you, Mr. Garbini.

I appreciate your testimony.

I would like to yield to the ranking member, Mr. Luetkemeyer, for introduction of our next witness.

Mr. LUETKEMEYER. Thank you, Mr. Chairman.

Mr. Bross is an owner of Chester Bross Construction Company and president of Mark Twain Redi-Mix in Hannibal, Missouri. Chester Bross Construction Company, founded in 1966, is an award-winning general contractor in the construction industry. From driveways to highways, Mr. Bross's company performs a wide variety of construction activities throughout the Midwest. Mark Twain Ready Mixed manufactures and delivers ready-mixed concrete and related products to commercial, residential and public projects.

Jeff is president of the Missouri Asphalt Pavement Association and vice chairman of the Missouri/Kansas Chapter of the American Concrete Pavement Association.

Jeff, thanks for being here today, and the committee looks forward to your testimony.

STATEMENT OF JEFFREY BROSS

Mr. BROSS. Thank you for having me. Good morning. Most of my points have been touched on at length here.

Chairman SHULER. Pull your microphone a little closer, please, sir.

Mr. BROSS. Can you hear me now? Okay.

Like I said, most of my points have already been touched on, so there is no reason to dwell on them.

We do ready-mixed and highway paving all over the Midwest. And our biggest concern is that we are taking a product that has taken years to get acceptability in the specifying industry and the contracting industry to where it—and it also improves the quality of the ready-mixed concrete in almost all cases. I don't know if that has been mentioned or not. And it has also been specified now as a requirement in certain projects for the benefits it provides to the material.

It also, as far as a hazardous situation, that has been expounded on, it obviously isn't when used in concrete. And to tie it to this Subchapter C is going to propose a liability that we are fairly certain we are not going to be able to sustain as far as insurance and bonding and things of that nature if we continue to use fly ash, because the way we understand it, the responsibility or liability is going to fall to us if it is declared hazardous and then lawsuits come out and all that down the line.

So I guess my quick, simple point is you have got a product that makes concrete better. Every time you put it in the concrete, you are using less portland cement, which means less carbon footprint going out the stacks of the cement plants and the kilns.

If you don't use the fly ash because of all this liability, you are going to have that much more to get rid of somewhere. That is being handled very well right now on a good quality-control basis. And I just I am kind of a commonsense guy. It just looks like we are here to—I don't even understand why we are talking about this. That is really all I got.

[The statement of Mr. Bross is included in the appendix.]

Chairman SHULER. That happens a lot here in Washington.

But you have a panel—you know, as a panel you are certainly—your input and expertise really helps us make much better decisions in the things that we are able to do.

And, you know, even within this panel, I can even hear differences of opinion, and that makes it even more difficult to come to some agreement on. And we are going to try to get through as many questions as we possibly can, that way you can go on about your business.

Dr. Benson, the State of Wisconsin has stronger regulations for disposal on the reuse of coal ash than most States do, but yet you double the national average. So what are you doing within Wisconsin that has tough regulations but actually doubles the national? Average, what are you doing? How are you able to educate?

I know, Mr. Garbini, we are talking about leaving it to the States because, I mean, heaven forbid, if one State says it is a hazardous waste, then that knocks everybody out. And so we got to find some uniformity.

And I know Mr. Adams, in his testimony, and we are on the same page talking about giving them the regulation under D; that way we can have uniformity. Because one State—I mean, I don't know which State, maybe the Pacific Coast side, if they want to decide it is a hazardous waste, then ultimately, we end up that it impacts everyone in the industry. And we talk about insurance, liability, litigation.

So what are you doing in Wisconsin that increases, doubles the amount of use but also have somewhat good regulations?

Mr. BENSON. Well, I would indicate that we actually do two things. We have a disposal regulation that mimics Subtitle D. And that provides us with a vehicle when we need to dispose of these materials that is safe and protective of the environment. It has been very effective. We actually at our modern disposal facilities haven't had a single environmental compliance issue with regard to groundwater in those modern facilities. So we have a code that is like Subtitle D, that provides safe containment of these materials.

The other thing that we have is we have vehicles in our regulation that allow us to use these materials. We recognize their value. We recognize the importance of using our resources wisely. And we developed a code, in collaboration with industry stakeholders, environmental stakeholders, and regulators, that allows us to use these materials in a very safe and wise manner that is both protective of the environment but also allows them to be used in construction.

So through those two vehicles, we have been very successful in increasing the use of coal combustion products and other industrial byproducts, while also ensuring that we protect the environment in disposal applications.

Chairman SHULER. I am going to recognize Mr. Luetkemeyer for his questions.

Mr. LUETKEMEYER. Thank you, Mr. Chairman.

Mr. Bross, during your testimony, you indicated that it improves the quality. Could you give me examples of how it improves the quality of the concrete?

Mr. BROSS. Well, some of these guys here are probably much more qualified technically.

Mr. LUETKEMEYER. I want real-world experience.

Mr. BROSS. When you use fly ash, in most instances, you get a higher strength material, and it is also more durable. You can use less cementitious material, which is going to affect your shrinkage and curling of your concrete. In like a large flat board pour, that makes a big difference in how much the concrete shrinks and curls, and things like that. It is hard on the—a lot of things. These guys can tell you.

And then there is also a silica reactivity, which I am not all that technical on. I just know that using fly ash in the concrete helps offset this alkali silica reactive—it is the aggregates, right, that cause it? And if you take it away, you have got this ASR problem down the road, where the concrete deteriorates. And they had a huge problem with it in Pennsylvania, I know, and in Texas, a lot of places around the country.

Mr. LUETKEMEYER. Whenever you are working with it and you are handling it and you are putting it into your mix, what are the

things that you do to protect your people and the environment around that? I am sure there are some sort of controls on that. Would you just elaborate just for a second?

Mr. BROSS. It is all controlled. It is air tight, basically. You have hoses hooked up to your truck before you open any valves. You open the valves. You put pressure to the tank, and you blow it up into a silo or a storage vessel. And that is vented into a pollution control device, a bag house, that is 99.99 percent efficient at trapping it, and none of it—essentially none escapes.

Mr. LUETKEMEYER. So, basically, handling is not a problem either?

Mr. BROSS. No, sir.

Mr. LUETKEMEYER. And it has never been—the scientific stuff here is—let me just wrap up my thoughts here.

The EPA folks are still here, and I think you have heard the testimony of the folks in the real world who deal with this every day. And we don't have any sound science that says this is a bad product.

During the testimony, EPA mentioned or agreed that it is an impoundment problem. I think that is where we need to focus.

I do have a concern about, Mr. Benson, and I think Mr. Gehrmann mentioned, that the EPA has pulled from the Web site information on recycling of this, is that correct? I would certainly like to know why EPA pulled that from their Web site when there has been no definitive ruling about this. I think it is very important. We are talking about recycling something here that I think is important to the environment. It is important to the industry and a lot of folks here.

So I would certainly appreciate that, Mr. Chairman. With that, I would yield back.

Chairman SHULER. Thank you.

Sir, I couldn't agree more with you from the standpoint I can't understand why they took that from the Web site. Let's hope that it is just a technical glitch, and it will be up next week. We are hoping that will be the case.

Ms. Cooper, you are the small business. I mean you exemplify everything about small business. How many employees do you have?

Ms. COOPER. Twenty-one.

Chairman SHULER. Twenty-one, a small business, that is perfect.

Tell me about the stigma. What is happening now? Tell me about the stigma that is happening in the industry now, but then what will be the bottom line if it is designated under Subtitle C?

Ms. COOPER. We see no deals. Everybody is in a wait-and-see mode. The EPA's actions, and we told them this prior to the rule coming out, have people laying off. There are fly ash marketers that are laying off. We have been able to retain our employees.

The markets get even more jittery when EPA does things that demonstrate they don't understand the markets, like taking down the Web site and suspending their support for the program without talking to partner agencies. If they would have talked to us ahead of time, we could have warned people.

But if there are beneficial-use deals that are in the mix, no one is going to take those deals seeing EPA do these type of things.

The industries that they are basing their assumption, that if it is a hazardous waste exemption, it is going to increase, are very different than ours. The chain of title is very different. And there are not as many small businesses in there that will not be able to withstand indemnifications and other things.

If it does go to a Subtitle C, I fully expect that ASTM and the gentleman next to me, who is with ACI in a volunteer capacity, will be telling people, you know, it is a hazardous waste in other settings. And you will have consumers, like in Missouri, if you look at the Corps of Engineers recently held a hearing, and numbers of people came out and even with a binder in there, they said we don't want fly ash in there because it is toxic. I expect that our industry will not survive, and it will not be able to be built back. You hear, by people who have more gray hair and not as good hair dressers as mine, that it has taken years to get to this point, and we won't be able to go back and resurrect it.

Chairman SHULER. Thank you, Ms. Cooper.

I appreciate everyone's testimony today.

I think that the EPA has listened today. I think that here is an opportunity for an entire panel. And I think there is an opportunity for us, whether it be through legislation, as the ranking member and I have been talking about. We have worked with some of you already on the legislation, and working with EPA.

Now, at this point in time, we have started the fight together; crossing the aisle, we have done that together. Now it is, how can we work together? And now has to be, how can we work with the EPA? How can we do this in order to make sure that we are all on the same page, that we can save the jobs, that we can protect the environment, we can lower our emissions footprint?

So now is the time for us to work together. And moving forward, there has to be a way that we can come to common ground, unite together under the fact that we want to do what is right for the environment, we want to do what is right for human health, but we also want to do what is right for our businesses as well and ensure that the small businesses have a voice. Your voice has been heard today.

And I would like to thank the ranking member and my colleagues.

And obviously, as you see, we have 5 minutes to go vote.

I ask for unanimous consent that the record be open for 5 days for members to submit their statements.

Hearing no objection, so ordered.

This hearing is adjourned.

[Whereupon, at 11:45 a.m., the subcommittee was adjourned.]

HEATH SHULER, NORTH CAROLINA
CHAIRMAN

BLAINE LUETKEMEYER, MISSOURI
RANKING MINORITY MEMBER

Congress of the United States
U.S. House of Representatives
Committee on Small Business
Subcommittee on Rural Development,
Entrepreneurship and Trade
2301 Rayburn House Office Building
Washington, DC 20515-0515

STATEMENT
Of the Honorable Heath Shuler, Chair
U.S. House Committee on Small Business
Subcommittee on Rural Development, Entrepreneurship, and Trade
Subcommittee Hearing: *"Coal Combustion Byproducts: Potential Impact of a Hazardous Waste Designation on Small Businesses in the Recycling Industry"*
Thursday, July 22, 2010

The Subcommittee has called this hearing so that Members might learn more about coal ash, the small businesses that turn coal ash into useful products, and the concerns these businesses have about proposed federal regulations that they believe may have a negative effect on their industry.

We will hear a lot of terms used in today's hearing—like CCB, CCR, CCP, CCW. In essence, these all refer to coal ash. What we will focus on in this hearing are the types of coal ash that are beneficially re-used.

Coal ash contains elements that can be harmful to the environment and to human health unless it is properly stored or disposed of. The environmental community has long called for increased federal regulation of coal ash in order to ensure greater protection. I am in complete agreement with this concept.

EPA has recently issued two proposals for regulating coal ash. One would regulate coal ash as a solid waste, and would provide very limited federal enforceability and may not provide adequate protection of the environment and human health. The other would list coal ash as a "special waste" under the hazardous waste subtitle in the Resource Conservation and Recovery Act—Subtitle C. This second option is the one we will focus on in today's hearing, since it has generated great concern among small businesses across the country.

These businesses, many of which are represented here today, have reason to believe that regulating coal ash under Subtitle C—even as a "special waste"—will open recycling operations to added litigation and a stigma that will discourage the production and use of products made with recycled coal ash. Some of these small businesses believe that these negative effects are already occurring within their industry.

If the predictions of those in the coal ash recycling business are accurate, EPA regulation of coal ash under Subtitle C will greatly harm a multi-billion dollar industry that provides thousands of American jobs and often results in reduced waste disposal and net carbon emissions.

I am eager to hear their testimony today, and the testimony from our EPA witness, Lisa Feldt, who will hopefully be able to shed additional light on this subject.

Testimony of Lisa Feldt
Deputy Assistant Administrator
Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency
Before the
Subcommittee on Rural Development, Entrepreneurship, and Trade
Committee on Small Business
United States House of Representatives

July 22, 2010

Mr. Chairman and members of the Subcommittee, thank you for the opportunity to testify today on the U.S. Environmental Protection Agency's (EPA's) coal combustion residuals regulatory development activities. My testimony provides a brief overview of our regulatory proposal and some of the major issues on which we are seeking public comment, particularly as it relates to the beneficial use of coal combustion residuals.

EPA'S REGULATORY HISTORY ON COAL COMUBSTION RESIDUALS

Coal combustion residuals (CCRs) are one of the largest waste streams generated in the United States, with approximately 136 million tons generated in 2008. Of this, approximately 34% (46 million tons) are landfilled; approximately 22% (29 million tons) are disposed of in surface impoundments; approximately 37% (50 million tons) are beneficially used; and approximately 8% (11 million tons) are placed in mines. CCRs contain constituents, such as arsenic, cadmium, and mercury, which can pose threats to public health and the environment if improperly managed. Thus, proper management of these waste streams is essential to protecting public health and the environment.

EPA has a long history of regulatory efforts regarding coal combustion residuals. Of particular note, is EPA's "Regulatory Determination on Wastes from the Combustion of Fossil

Fuels," issued in May of 2000, which conveyed EPA's determination that coal combustion residuals did not warrant regulation as a hazardous waste under subtitle C of the Resource Conservation and Recovery Act (or RCRA). EPA also concluded that federal regulation as a non-hazardous waste under subtitle D of RCRA was appropriate; EPA did not issue regulations at that time. With respect to the beneficial use of coal combustion residuals, EPA determined that the beneficial use of coal combustion residuals did not pose a risk and did not require federal regulation. EPA also determined that the placement of coal combustion residuals in minefill operations should be regulated under subtitle D of RCRA, the Surface Mining Control and Reclamation Act (SMCRA), or both. Finally, the Agency noted that if additional analysis or information became available that would indicate the need for regulation under subtitle C of RCRA, that the Agency would revise the Regulatory Determination.

After the Regulatory Determination, EPA continued to collect additional information and conduct additional analyses as part of its effort to develop regulations; including additional damage cases, risk modeling, updated information on current management practices and state regulations associated with the disposal of CCRs, petitions from citizens and environmental groups for EPA to develop rules for the management of CCRs, an industry voluntary agreement on how they would manage CCRs, and a proposal from environmental and citizen groups for a CCR rule. As a result of this new information and analyses, and how it could impact the Agency's May 2000 Regulatory Determination, EPA decided to make this information available for comment. Thus, in August 2007, EPA made much of this information available for public comment through a Notice of Data Availability. We received nearly 400 comments on this information and analyses.

The catastrophic failure of a surface impoundment retaining wall in Kingston, Tennessee in December 2008 and the resulting spill of coal ash highlighted the issue of impoundment stability. While our previous regulatory actions had not addressed this particular issue, we determined that our new regulatory efforts had to be designed to prevent future catastrophic releases, as well as other types of damages associated with the disposal of coal combustion residuals in landfills and surface impoundments. After the catastrophic release of coal ash at the Tennessee Valley Authority's (TVA's) Kingston's plant, EPA's Administrator Jackson committed to issue regulations that would address the management of coal combustion residuals.

EPA'S PROPOSED RULE FOR COAL COMBUSTION RESIDUALS

On June 21, 2010, EPA proposed regulations for coal combustion residuals under RCRA to address the risks from the disposal of such wastes in landfills and surface impoundments generated from the combustion of coal at electric utilities and independent power producers. However, because regulating coal combustion residuals raises many significant issues and because EPA wants to ensure that the ultimate decision is based on the best available data and is taken with the fullest possible extent of public input, EPA has co-proposed two alternative regulatory options, and is taking comment on a wide cross-section of issues.

Under the first regulatory alternative, EPA would reverse its May 2000 Bevill [1] Regulatory Determination regarding coal combustion residuals and list these residuals, when destined for disposal in landfills or surface impoundments as "special wastes" subject to regulation under subtitle C of RCRA, which would create a comprehensive program of federally

[1] The Bevill exclusion [Section 3001(b)(3)(A)(i)] of RCRA excluded certain large volume wastes generated primarily from the combustion of coal or other fossil fuels from being regulated as a hazardous waste under subtitle C of RCRA, pending completion of a Report to Congress required by Section 8002(n) of RCRA and a determination by the EPA Administrator either to promulgate regulations under RCRA subtitle C or to determine that such regulations were unwarranted.

enforceable requirements. Under the second alternative, EPA would leave the Bevill Regulatory Determination in place and regulate the disposal of CCRs under subtitle D of RCRA by issuing national minimum criteria, which would be narrower in scope and could be enforced by the states and by private citizen suits. Under both alternatives, EPA is proposing to establish dam safety requirements to address the structural integrity of surface impoundments to prevent future catastrophic releases of coal combustion residuals.

In addition, EPA is not proposing to change the May 2000 Regulatory Determination for coal combustion residuals that are beneficially used. These residuals are currently exempt from hazardous waste regulation. EPA continues to believe that the Bevill exclusion should remain in place for coal combustion residuals that are beneficially used in an environmentally-sound manner because of the important benefits to the economy and the environment including, for example, reduced air pollution and lower greenhouse gas emissions. In addition, the management scenarios for these materials are very different from the risk case being considered for the disposal of coal combustion residuals in surface impoundments and landfills. EPA's proposal, however, makes clear that EPA does not consider coal combustion residuals placed in sand and gravel pits, quarries, and other large fill operations to be beneficial use. EPA views this as disposal and would regulate it under whichever regulatory option EPA finalizes.

EPA has learned a great deal regarding the beneficial use of coal combustion residuals since the May 2000 Regulatory Determination. In addition, there has been a significant increase in the reuse of coal combustion residuals, with development of commercial sectors that depend on the beneficial use of these materials. As already noted, the beneficial use of coal combustion residuals provides significant environmental benefits and new applications may provide even

greater benefits, with new studies on their use being conducted. Some of this confirms or strengthens EPA's views on the benefits of coal combustion residuals. Yet, on the other hand, some information indicates that certain uses may raise concerns and merit additional attention.

The area of beneficial use is quite complex, in that some of these uses are in an encapsulated form, while other uses are in an unencapsulted form. EPA believes that the great bulk of beneficial uses, particularly in an encapsulated form, like in concrete and wallboard, do not raise concerns and offer important environmental benefits. However, some questions have been raised about the use of coal combustion residuals in an unencapsulated form. Thus, EPA's proposal is seeking additional information, and requesting specific comment on certain aspects of the beneficial use of coal combustion residuals. For example, EPA is seeking information on:

- whether unencapsulated uses of coal combustion residuals warrant tighter control and why such tighter control would be appropriate;
- whether it is necessary to better define beneficial use or provide detailed guidance on the beneficial use of coal combustion residuals to ensure protection of human health and the environment;
- whether there are incentives that could be provided that would increase and further encourage the amount of coal combustion residuals that are beneficially used; and
- information and data on the best means for estimating current and future quantities and changes in the beneficial use of CCRs.

A full list of the information we are seeking comment on related to beneficial use can be found in EPA's proposal at http://www.epa.gov/osw/nonhaz/industrial/special/fossil/ccr-rule/index.htm.

One of the issues that commenters have raised to EPA is that any regulation of the large-scale disposal of coal combustion residuals under subtitle C of RCRA will impose a stigma on their beneficial use and thus significantly curtail these beneficial uses. EPA has questioned this assertion and discussed in the preamble to the proposed rule that if subtitle C of RCRA were selected as the regulatory option, disposal of coal combustion residuals would become more expensive, and thus, beneficially using coal combustion residuals would become more attractive relative to disposal. Past experience, as discussed in EPA's proposal, suggests that increasing the costs of disposal as a result of subtitle C regulations would create a strong economic incentive for increasing diversion to beneficial uses. However, because this issue has been raised, and because EPA wants to continue to encourage the environmentally sound beneficial use of coal combustion residuals, EPA is seeking comment and data on this issue.

EPA has also taken a number of actions in the proposal that we believe would mitigate any potential for inadvertent stigma from the regulation of CCRs. First, we have proposed to retain the Bevill exclusion for beneficially used CCRs, so the regulatory status of these would remain unchanged regardless of whatever option is ultimately adopted. Second, we have proposed to identify coal combustion residuals as a "special waste" so as not to unintentionally stigmatize the beneficial use of coal combustion residuals. In addition, in our proposal, we specifically ask for comments providing suggestions or methods by which we could reduce any potential impact that might indirectly arise. We are also seeking information on actual instances

where stigma has adversely affected the beneficial use of CCRs and the causes of these adverse effects and welcome ideas on how to best estimate any potential effects for purposes of conducting regulatory impact analyses and any data or methods that would help in this effort.

CONCLUSION

The regulation of coal combustion residuals raises complex issues – from the scientific analyses to public and regulatory policy. EPA's efforts are designed to ensure that our final decision regarding the appropriate management framework for coal combustion residuals is based on the best available information and with the fullest possible public input. Thank you for the opportunity to discuss these important issues with you today.

Testimony of Craig H. Benson, PhD, PE, DGE
Wisconsin Distinguished Professor, University of Wisconsin-Madison

House Small Business Subcommittee on
Rural Development, Entrepreneurship and Trade

22 July 2010

Thank you for the opportunity to share with this Committee my experience and opinions regarding coal combustion products (CCPs), and their beneficial use in sustainable construction. My name is Dr. Craig H. Benson, PhD, PE, DGE and I am a Professor of Geological Engineering and Civil & Environmental Engineering at the University of Wisconsin-Madison. I am also Director of the Recycled Materials Resource Center at the University of Wisconsin-Madison and Chair of Geological Engineering. I teach courses that pertain to sustainable construction and management of byproducts, amongst other topics. I also conduct research and development on the safe and wise use of industrial byproducts in sustainable construction as well as the environmentally sound management of wastes. I have been involved in scientific research and engineering practice for more than 25 years.

For 20 years, I have been conducting research on sustainable construction with industrial byproducts, including CCPs such as fly ash, bottom ash, and flue-gas desulphurization (FGD) residuals. Over the last decade, CCPs have become a large part of my research program because of the many ways in which they can be used safely, wisely, and economically in sustainable construction. This research has been supported by a broad distribution of stakeholders, including the US government, state governments, local governments, and industry. I strongly believe that using CCPs for infrastructure construction is advantageous for the nation. The most important advantages include creation of infrastructure that is more resilient and has longer service life while simultaneously reducing the energy consumed, water used, and greenhouse gases emitted for infrastructure construction. The US infrastructure is enormous and constitutes a major portion of our nation's capital investment and energy usage each year. Consequently, changes in regulations that may affect use of CCPs in infrastructure construction should be undertaken with great caution and care.

What are coal combustion products (CCPs)?

Coal combustion products (CCPs) generally consist of fly ash, bottom ash, boiler slag, and flue-gas desulphurization (FGD) residuals. Each is described in the following.

Fly ash. Fly ash is a fine-textured particulate collected from the off gas at coal-fired power plants to control air pollution. Although fly ash is a byproduct of controlling air pollution, scientific research and engineering practice have shown that fly ash has many useful characteristics as a construction material. Many fly ashes are cementitous, meaning that they can be used to bind particles together in a manner analogous to a conventional cement (e.g., Portland cement used in concrete). Fly ashes also are rich in calcium, silicon, and aluminum, and thus can be a good source of these elements in industrial processes such as Portland cement production. Thus, while fly ash may be considered a waste or byproduct from one industrial operation, fly ash is also a useful resource for other industrial operations (e.g., concrete production) that can be used in lieu of conventional materials that need to be mined

and processed. By using fly ash in place of these conventional materials, energy and water are saved and greenhouse gas emissions are reduced. Improved engineering characteristics (e.g., durability, strength, etc.) can also be achieved.

Bottom ash and boiler slag. Bottom ash is a coarse-textured particulate residual of coal combustion that is collected from the bottom of a boiler. Boiler slag is a solid residual that collects on the boiler during combustion that is generally found as a coarse particulate. Bottom ash and boiler slag are generated in much smaller volumes than fly ash. Most bottom ash looks like sand largely because bottom ash is similar chemically to sand. Bottom ash is used in construction in the same manner as sand, i.e., as a foundation material, a backfill material, and as drainage material. Using bottom ash or boiler slag in lieu of sand or other natural aggregates precludes the need to mine sand from the earth and process the sand so that it has suitable engineering characteristics. Consequently, when bottom ash or boiler slag is used in lieu of sand or other coarse aggregate, the energy use and greenhouse gas emissions associated with mining and processing sand are avoided. Additionally, fewer quarries for sand and gravel are needed, which improves land and resource stewardship.

FGD residuals. FGD residuals are created as a byproduct of waters containing lime or limestone that are used to remove sulfur compounds from off gases to reduce air pollution (e.g., reduce 'acid rain' by removing SOx compounds). FGD residuals consist of gypsum (hydrated calcium sulfate) created when the calcium binds with the sulfur compounds in the presence of water. FGD residuals also contain small amounts of impurities. Because FGD residuals consist almost exclusively of gypsum, they are used in lieu of natural gypsum in industrial processes. The most common use is for manufacturing wallboard for building construction. Using FGD residuals in lieu of mined gypsum reduces energy use, water use, and greenhouse gas emissions. Additionally, fewer gypsum mines are required, which improves land and resource stewardship.

Have the risks changed since CCPs were designated as non-hazardous materials?

The chemical make up of fly ash depends on the coal used for combustion, the method used for combustion, the method used for collection, and ancillary processes that are employed for air pollution control (e.g., carbon injection). These factors change over time with technological innovation. However, the general characteristics of fly ashes have not changed dramatically since CCPs were originally designated non hazardous by Congress. Consequently, the risk of using fly ash in construction today is no different than it was decades ago. Similar statements can be made regarding bottom ash, boiler slag, and FGD residuals.

Fly ashes contain a variety of elements (e.g., calcium, aluminum, selenium, chromium) as do conventional earthen materials used in construction. Some of these elements are present in larger amounts in fly ash than in conventional earthen materials; others are lower. However, none of the amounts typically are high enough (or sufficiently mobile) for fly ash to be deemed "hazardous" as defined in the Resource Conservation and Recovery Act (RCRA). Thus, there is no scientific reason to manage CCPs as hazardous wastes.

Although CCPs have been designated as non-hazardous, and generally would not be considered hazardous when evaluated by the metrics in RCRA, they are not inert materials (i.e., non-hazardous does not imply inert). For example, cement reactions are initiated when many fly ashes are contacted with water in the same manner that cement reactions occur when Portland cement is mixed with water. These reactions create heat and alkalinity as the cements

are formed. In addition, contacting CCPs with water can transfer elements in the CCP solid to the water, where they can be more mobile. Thus, like all construction materials, CCPs should be deployed in properly engineered applications using appropriate safety precautions that result in no adverse impact to the environment. Applications where CCPs are used in a dry environment (wallboard) or in a cemented monolithic environment (e.g., concrete) tend to have very low release and pose virtually no risk to the environment. In most cases, these applications have virtually no measure release.

Even in applications where releases may occur (e.g., stabilized base course in a roadway), the release needs to be considered relative to releases from conventional construction materials and to environmental standards. Because all construction materials are comprised of elements derived from the earth, they have the potential to release elements to the environment when contacted by water. Thus, a CCP may adversely affect the environment relative to a conventional construction material only if the CCP releases elements in a greater amount. Research has shown that some elements are released from CCPs in lesser amounts than from conventional construction materials, which means that CCPs may have *less* impact on the environment than conventional construction materials. In other cases, CCPs can release elements in greater amounts than a conventional construction material. In such cases, an adverse impact to the environment occurs only if elements are released at levels above environmental standards. Research that I have conducted, and the research of others, have shown that CCPs used in properly engineered applications generally do not release elements to the environment in amounts that exceed environmental standards.

Will the "hazardous waste" stigma affect beneficial use?

When we use CCPs as a resource, we realize significant advantages, notably reduced consumption of energy and water and lower greenhouse gas emissions. In some cases we obtain a superior product when fly ash is used in lieu of conventional construction materials. For example, roadway systems constructed with fly ash tend to be more durable and have longer service life.

Despite these advantages, not all industrial byproducts are beneficially used. There are many factors that affect whether an industrial byproduct will be selected in place of a conventional material. One of the most important factors is concern regarding potential environmental impacts and long-term liability. Major inroads have been made to address this concern over the last two decades using scientific principles and engineering methods. Test procedures have been developed, evaluation procedures have been formulated, and computer models have been created to evaluate risks and to alleviate concerns regarding environmental impacts and liabilities. However, none of these science-based principles and tools will overcome the psychological impact of CCPs being deemed a hazardous waste. An exemption for beneficial use will have virtually no effect on this psychological impact. The "hazardous" designation will scare users and incite liability, and thereby decimate beneficial use of CCPs.

Some have proffered that a hazardous designation coupled with a beneficial use exemption will increase the amount of CCPs that are beneficially used in a manner analogous to the reduction hazardous waste volume that occurred when RCRA hazardous waste rules were originally developed. My experience suggests that this outcome is unrealistic. Beneficial use is contingent on infrastructure owners accepting CCPs in their infrastructure, which is influenced strongly by owners' perceptions of risks. The beneficial use community has struggled for years to overcome owners' concerns regarding liability for industrial byproducts that are not

designated hazardous. This struggle can only become much more difficult if a hazardous designation is instituted, even with a beneficial use exemption. There is no basis to believe that infrastructure owners will accept that the risks of using CCPs in infrastructure are minimal when essentially the same material is deemed a hazardous waste in a different setting. Indeed, evidence in this regard has already been realized as public works agencies in California and Maryland have banned use of CCPs in their infrastructure projects. Manufacturers of competing products and materials that do not include CCPs have also taken advantage of the hazardous waste stigma by advertising that their products and materials do not include hazardous waste.

I surmise that beneficial use of all industrial byproducts will diminish if CCPs are deemed hazardous waste. The logical inference from the perspective of a potential user is "Will the industrial byproduct I am using today be designated as a hazardous waste tomorrow? How will this affect my long-term liability?" The logical decision from the perspective of the user is to avoid beneficial use of industrial byproducts altogether. The impact on the nation will be greater energy and water consumption, greater greenhouse gas emissions, and poorer resource stewardship.

What effect will diminished beneficial reuse have on energy, water use, and greenhouse gas emissions?

My research group has been conducting a study to assess how cessation of beneficial use of CCPs will affect energy consumption, water usage, and greenhouse gas emissions. Although our study is not yet final, the findings are startling. Using CCPs in sustainable construction results in:

- saving 159 trillion Btu of energy annually,
- reducing water use by 32 billion gallons annually, and
- reducing greenhouse gas emissions by 11 million tons of CO_2 each year.

In more tangible terms, using CCPs in sustainable construction results in:

- saving the energy equivalent of 1.7 million US households annually,
- reducing water use in an amount equivalent to 31% of California's annual water use, and
- reducing greenhouse gas emissions equivalent to 1.9 million passenger cars each year.

Others recognize these savings. For example, the Kyoto Protocol accepts the reduction in greenhouse gas emissions from beneficial use of CCPs.

The stigma of a hazardous designation, even with a beneficial use exemption, will substantially reduce these benefits achieved by using CCPs in sustainable construction. A financial impact will also be realized. My research group estimates that using CCPs in sustainable construction results in a cost savings between $5 billion and $10 billion annually.

Are regulations for CCPs needed?

Regulations are needed to ensure that CCPs are managed and used in an environmentally sound manner. A means to ensure that these regulations are enforced uniformly is also needed. However, this does not imply that CCPs should be managed as hazardous waste in

accordance with Subtitle C of RCRA. The containment technologies stipulated in Subtitle D of RCRA (e.g., single composite liners, leachate collection systems, monitoring, etc.) are sufficient to ensure that CCPs that are not beneficially used are managed in an environmentally sound manner. Amending RCRA to permit federal control over CCP disposal using RCRA Subtitle D technologies is a logical solution that would ensure uniform application of regulations, protect the environment, and preclude the demise of beneficial use.

Statement of Thomas H. Adams, Executive Director, American Coal Ash Association

House Small Business Subcommittee on Rural Development, Entrepreneurship and Trade

July 22, 2010

"Is Coal Combustion Product Recycling an Endangered Industry?"

Mr. Chairman, my name is Thomas Adams. I am the Executive Director of the American Coal Ash Association (ACAA). I would like to thank you for the opportunity to speak to you and the subcommittee today on a major recycling success story that is solving serious environmental concerns while brining significant economic benefits to the US economy. Founded in 1968, the ACAA's mission is to encourage the use of coal combustion products (CCP) in ways that simultaneously benefit the environment, are technically appropriate, commercially viable, and contribute to a more sustainable society.

Beneficial use, another term for recycling, means many things to many people. To most people it means finding ways to use as much of our resources in ways that protect human health and the environment at a reasonable cost, and to make finished products that perform as well or better than products made with 100% virgin materials. By maximizing beneficial use of CCP we help preserve virgin resources for use by future generations while minimizing the effects of current economic development on the environment.

The coal combustion product family consists of materials remaining after the combustion of coal in coal fueled power plants. The primary products are fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) gypsum. In the most recent Production and Use Survey (1) conducted by the ACAA for 2008, approximately 136 million tons of CCP were generated. CCP is the second largest waste stream in the US following only municipal solid waste. Of this 136 million tons of CCP generated, approximately 44% went into a variety of beneficial uses. This means 60 million tons of CCP was recycled in 2008 rather than being sent to disposal facilities. Since 2000 the recycling rate has risen from 30% to 44%. In its most recent Economic Assessment of the impact of coal ash on the US economy, the American Coal Council determined that the annual benefit to the US economy is in the range of $9 to $10 billion.

Today I would like to focus on some important beneficial uses of CCP. Fly ash is a fine powder-like substance with much the same consistency as Portland cement. It is collected in power plants and handled much like Portland cement. Because of its mineral constituency it is a valuable raw material in the manufacture of Portland cement for many producers. Depending on the quality and consistency of the fly ash, it is also a very valuable supplementary cementitious material (SCM) for the manufacture of concrete products, being used to replace and optimize Portland cement in concrete mixtures.

FGD gypsum is produced when flue gases are scrubbed in power plant stacks to remove sulfur dioxide (SOX) and nitrogen oxide (NOX) from emissions into the environment. Scrubbing by using lime or limestone in forced oxidation processes produces a synthetic gypsum which has purity equal to or greater than mined gypsum.

Fly ash is used as a raw material in cement manufacture due to the minerals present, mostly silicates. The use of fly ash as a raw material means that there is less mining of virgin sources to obtain those minerals silicates. Cement manufacturers balance the availability of fly ash with the needed chemical composition with the availability of material from virgin sources. The cement producers consumed 4.2 million tons of fly ash in 2008.

Fly ash is also used in concrete manufacture as a supplementary cementious material or SCM. The 2008 Production and Use Survey showed that 14 million tons of fly ash went into concrete products. The use of fly ash in concrete mixtures allows for a reduction in the quantity of Portland cement required for achieving desired results. The material is mistakenly called a cement replacement for his use. The reality is that there are performance characteristics in concrete structures that can only be achieved by the use of fly ash or other SCMs. Portland cement is important but cannot always provide the characteristics that create the high-performance and long-term durability in concrete structures. High performance can mean many things such as low permeability reducing water migration which can initiate corrosion of reinforcing steel, high compressive strength which enables structures to carry heavy loads with smaller members, or resistance to aggressive environments which attack the concrete matrix resulting in reduced service life.

Having spent many years in the ready mixed concrete industry, I can personally attest to the importance of having a valuable tool such as fly ash available to solve the performance requirements in a wide variety of construction projects. Today producers are taking the use of fly ash and other SCMs into new and expanded applications. Innovation is on a fast track.

A major benefit from the use of fly ash to optimize concrete mixtures is reduction of carbon dioxide emissions. When fly ash is used in a concrete mixture reducing the amount of Portland cement required, less CO2 is emitted as the quantity of cement manufactured is reduced. By avoiding 1 ton of cement manufacture, approximately 0.9 tons of CO2 are not emitted by the cement plant. Since 2000 over 117 million tons of carbon dioxide emissions have been avoided by the use of fly ash in concrete mixtures. There remains a large capacity in the concrete industry to increase the amount of fly ash used. One of the top environmental priorities of President Obama's administration is reduction of green house gases. The concrete industry has been doing its part to achieve reductions for some time. With the proper incentives, this reduction can be maintained and accelerated.

In 2008 8.5 million tons of FGD gypsum went into wallboard products. Approximately 35% of the wallboard manufactured in the United States is made with FGD gypsum. Wallboard manufacturers have intentionally located plants close to utilities to take advantage of logistical benefits. In some cases the material is moved by conveyor from the power plant to the wallboard plant. This process is more sustainable than the use of mined gypsum as mining, handling, and transportation impacts are virtually eliminated. This also results in CO2 reduction from elimination of mining and handling, and transportation.

There are other important markets for CCP beneficial use that I will not mention today due to time constraints. A common thread among all of these uses is the achievement of the mission of the ACAA in environmental safety, technical performance, economic viability, and contribution to a more sustainable society.

So what would endanger the continued successful beneficial use of these products?

In an effort to create regulations for the disposal of coal combustion products, the US Environmental Protection Agency (EPA) has published a proposal which contains an option which would treat CCP as a hazardous waste when destined for disposal under Subtitle C of the Resource Conservation and Recovery Act of 1976. The agency has expressed a preference for this option since it provides EPA with the authority to enforce disposal regulations. Subtitle D of RCRA, intended for non-hazardous wastes, places enforcement authority with individual states. EPA suggests that certain beneficial uses of CCP could be exempted from hazardous waste regulation. Therefore beneficial use in cement, concrete, and wallboard would continue though the same materials intended for disposal would be considered to be hazardous. We believe this "hazardous" designation would create a stigma resulting in rejection by the market place for the following reasons.

A primary concern in the market is liability exposure. Unfortunately our laws permit tort activity even when there is no evidence of damage. (The concrete industry is particularly sensitive to this having survived a siege of suits in southern California known as the "sulfate wars".) In discussions with engineers, contractors, and concrete producers over the last several months, it is clear that the use of fly ash would be severely curtailed due to fear of tort or class action suits. Many in the concrete industry do not believe EPA's assertion that the exemption would provide all the protection needed. Many do believe that a lawyer could make a simple argument to a jury that the fly ash in the disposal facility has exactly the same physical and chemical characteristics as the fly ash in the concrete in a home, hospital, daycare center, or school. Therefore if it is hazardous in the disposal facility, it must be hazardous in those structures thereby opening the door to financial claims. Even if a claim is found to be minimal, the costs of legal defense are something firms want to avoid.

The stigma of CCP as a hazardous waste also opens the possibility of negative marketing by suppliers of competitive materials. We have already seen examples in markets for shingles, bricks, and concrete blocks of advertising which attacks products containing CCP saying, "Our products do not contain hazardous waste. Do yours?" The public will always opt for materials that do not have the taint of some sort of hazardous status.

By placing CCP for disposal under hazardous waste rules, the efforts of entrepreneurs to bring new products to the market allowing the use of disposed CCP are effectively halted. Once CCP is placed in disposal it is a hazardous waste. New processes are being developed that would use large quantities of CCP some of which could come from disposal sites. The ability of these entrepreneurs to develop commercially competitive products would be crippled if they could not take advantage of the most economically feasible sources. Again, markets given a choice between products containing a hazardous component versus products with non-hazardous components will opt for the non-hazardous option.

Venture capital needed to get new businesses related to CCP beneficial use would be more difficult to obtain. Some ACAA members who have been relying on such funding report hesitation from their financial sources.

The beneficial use of coal combustion products across the country is being affected by the mere shadow of EPA hazardous waste regulations. Many of the affected entities are small businesses and entrepreneurs who are driving the effort to increase recycling. A few examples follow.

- CalStar Products opened a plant in Wisconsin to manufacture bricks and pavers from fly ash. Their process uses fly ash as a primary ingredient and consumes 85% less energy that used in producing traditional clay bricks. The Brick Industry Association has published comments that infer safety concerns because the brick is made with "hazardous wastes".
- A large manufacturer of shingles for residential roofing, Reed Minerals, a division of Harsco, had to threaten legal action against a proposed advertising campaign of a competitor. The campaign theme was "Our shingles do not contain hazardous waste. Do yours?"
- Colorado State University does research on coal combustion products. A utility that furnishes coal ash samples for this research has informed the university that no samples will be furnished should the EPA promulgate a hazardous waste rule of any kind.
- Anne Arundel County in Maryland has prohibited the use of fly ash in county construction projects pending EPA's final rule.
- The Los Angeles Unified School District has stopped allowing the use of fly ash in all LAUSD projects pending EPA's final rule.
- Calera, an emerging technology company based in California, is researching alternatives to fly ash for the manufacture of construction aggregates and cement supplements to avoid the requirements of processing a hazardous waste.

The EPA actually states in their June 21, 2010 proposal that beneficial use will increase under a Subtitle C hazardous waste regulations. The agency believes utility companies will be financially motivated to find ways to treat and handle CCP so market acceptance increases. Again, the markets have told the ACAA that any form of Subtitle C rule will stigmatize CCP and cause users to turn to other materials.

The stigma created by a hazardous waste regulation could have other unintended consequences. For example, insurance underwriters may include exclusion for projects utilizing CCP when renewing professional liability insurance for designers and general liability insurance for contractors. This would have a chilling effect on beneficial use regardless of EPA claims.

Mr. Chairman, the American Coal Ash Association Board of Directors recently passed a resolution (attached) calling for national standards for the regulation of coal ash disposal under Subtitle D of RCRA. The same resolution calls states the association opposition of any form of Subtitle C regulation.

The requirements for disposal facilities receiving coal combustion residuals are virtually identical under either of the EPA's proposed rules. Therefore it makes sense to avoid designating these materials as hazardous wastes for any reason and risk loss of a major environmental success story which contributes to our economy and helps create a more sustainable society. Subtitle C of the Resource Conservation and Recovery Act of 1976 is for truly hazardous waste. Since coal combustion residuals do not fail the characteristic tests which would qualify them to be labeled as hazardous, and none of the cited damage cases are a result of beneficial use, there is no justification for the assault on the beneficial use that is contained in the EPA proposal. Regulation of disposal under Subtitle D provides sufficient protection to human health and the environment without implying a danger that has yet to be proven.

EPA has stated publically that Subtitle D regulations are sufficient for coal combustion residual disposal (2). However a primary reason the EPA to favors Subtitle C regulations is that enforcement authority lies with the EPA under Subtitle C while enforcement authority under Subtitle D is resides with the states. The answer to resolving this concern is to amend the Resource Conservation and Recovery Act of 1976 to provide enforcement authority for the disposal of coal combustion residuals under Subtitle D to the US Environmental Protection Agency.

Respectfully,

Thomas H. Adams
Executive Director
American Coal Ash Association, Aurora, CO

(1) 2008 Coal Combustion Product Production & Use Survey Report, American Coal Ash Association
(2) Matthew Hale, Director, U.S. EPA Office of Resource Conservation and Recovery, to the Environmental Council of the States, September, 2009

Attachment: ACAA Board of Directors Resolution

Attachment

Resolution of the American Coal Ash Association

The Board of Directors of the American Coal Ash Association ("the ACAA"), a trade organization established in 1968 and devoted exclusively to encouraging beneficial uses of coal combustion products ("CCP") in ways that are beneficial to the environment, economy, and society, conducted a meeting on April 12, 2010, at which time the Directors duly adopted the following resolution.

WHEREAS, the ACAA has considered the salient features of changes to regulation of coal combustion byproducts ("CCB") under the Resource Conservation and Recovery Act ("RCRA") of 1976;

WHEREAS, ACAA members are engaged daily in the beneficial use of CCP and thousands of green jobs within the CCP industry depend upon meeting numerous standards and specifications set by ASTM International ("ASTM"), the American Concrete Institute ("ACI"), the American Association of State Highway and Transportation Officials ("AASHTO"), the U.S. Environmental Protection Agency ("EPA"), and other state and local agencies;

WHEREAS, EPA has discussed proposing to regulate CCB under RCRA under either Subtitle C - Hazardous Waste, Subtitle D - Non-hazardous waste, or a "hybrid" approach that would include some form of Subtitle C regulation;

WHEREAS, numerous states, ASTM, ACI and AASHTO have signaled in written correspondence to EPA that a Subtitle C regulatory approach, including a hybrid approach, would have negative impacts upon beneficial uses of CCP;

WHEREAS, ACAA agrees that regulating CCB under Subtitle C of RCRA, including under a hybrid approach, would have negative impacts upon beneficial uses of CCP;

WHEREAS, implementation of CCB rules under Subtitle D would occur sooner than under Subtitle C, thousands of CCP green jobs would be saved and negative impacts to the beneficial uses under Subtitle C would be avoided; and,

WHEREAS, ACAA supports regulation of CCB under Subtitle D of RCRA;

The following resolutions were offered, seconded, and adopted.

BE IT RESOLVED that the Directors of ACAA support federal regulation of CCB under Subtitle D of RCRA; and,

BE IT FURTHER RESOLVED that the Directors of ACAA oppose regulation of CCB under Subtitle C of RCRA

CERTIFICATION

I, the undersigned, Secretary, do certify that the foregoing is a true exact and correct copy of a resolution adopted at a lawfully held meeting of the trade organization on the

12th day of April 2010.

Charles Price
Signature

Charles Price
Print Name

HOUSE SMALL BUSINESS COMMITTEE
RURAL AND URBAN ENTREPRENEURSHIP SUBCOMMITTEE
HEARING "Coal Combustion Byproducts: Potential Impact of a Hazardous Waste Designation on Small Businesses in the Recycling Industry"
July 22, 2010

Testimony of Lisa Cooper
Senior Vice President and Owner of PMI Ash Technologies, LLC

Chairman Shuler, Ranking Member Luetkemeyer, distinguished Members of the Committee, thank you for the invitation and opportunity to testify on the most critical issue for our small business -- the Environmental Protection Agency's (EPA) June 21, 2010 proposal to regulate the beneficial use of coal combustion products (CCPs). Our small business is PMI Ash Technologies, LLC (PMI) headquartered in Cary, North Carolina which focuses on environmental solutions to maximize the recycling of CCPs into concrete.

i. Introduction to PMI Ash Technologies

We are a small business with less than 25 employees. We develop innovative environmental solutions which solely focus on fly ash recycling in concrete. PMI develops, patents, commercializes, and deploys sustainable solutions which have avoided millions of tons of fly ash from being disposed of in landfills. One of our better known environmental solutions is Carbon Burn-Out (CBO) technology which utilizes a proprietary fine particle fluid bed to reduce a fossil plant's multi-media footprint. We also have developed solutions related to concrete blocks, specialty valves and solutions for different types of ash.

As long as coal is part of our nation's generation mix, we at PMI seek to reduce a fossil power plant's environmental footprint. We do this by focusing solely on one coal combustion by-product - fly ash. Fly ash receives most of the contaminants which are extracted from a fossil power plant's emissions via newly installed air pollution control devices. Most of these contaminants end up on the ash. PMI's innovative technologies work with air pollution control equipment providing a boost in fly ash sales into the concrete market. We seek to make all of our technologies sustainable. In certain applications, we can recycle heat from the fly ash to reduce coal burned at the fossil plant. In other applications, we can recycle other substances to reduce consumption.

One of our technologies, known as CBO, has been in commercial use since 1999. PMI's patented technology uses fly ash as a renewable or recurring feedstock to produce beneficiated fly ash suitable for use as a partial replacement for Portland cement in concrete and blended cements. The process combusts fly ash from the power plant in a fluidized bed, extracting the

residual energy content of the fly ash to fuel the beneficiation process, returning useful heat to the power plant. (See Attachment A – brief video of PMI's process).

PMI's technology accomplishes this in a manner where you never see the ash, because it is all enclosed in pipes, reducing particulate emissions. This allows a fossil plant to reduce its air, carbon, and solid waste footprint while using the fly ash to generate an additional 2 to 3 megawatts of generation or comparable fuel savings. (See Attachment B – brief video segment from the Profile Series highlighting one of PMI's innovative technologies).

Significant third party verification of carbon reductions occurred when a state regulatory scheme certified and verified carbon credits for two of the four PMI plants in commercial operation. (See Attachment C – regulatory documentation). In a carbon constrained environment, use of cementitious materials as a partial replacement of Portland cement plays an important role in producing real quantifiable offsets in manners which are safe for human health and the environment.

As communities and our society face energy challenges, existing coal plants are continuing to explore ways to reduce their multi-media footprint. CBO allows for sustainable use of a by-product – fly ash. It allows local stakeholders to avoid adding to landfills. It allows for implementation of additional air pollution control devices at power plants while at the same time recycling the fly ash in a safe manner – for use in concrete. Without the CBO technology, fly ash at these existing coal plants could not be used as a partial replacement for Portland cement. Incorporation of local fly ash into the local economy improves local green building supplies by making the concrete less permeable and more durable. CBO creates approximately 180 jobs during the construction of the CBO and 9 direct and 35 indirect high paying permanent jobs within the local market. Finally, the carbon footprint for the local community is reduced.

The significant energy, environmental and economic benefits resulting from the use of CBO and fly ash include:

1. PMI's beneficiation process extracts valuable energy from fly ash and makes it available to generate electricity, thereby increasing power plant efficiency and reducing coal use in proportion to the energy recovered from the fly ash.
2. PMI's beneficiation process reduces facility-wide mercury emissions while boosting ash sales even after activated carbon has been added to the power plant to reduce mercury emissions. (See Attachment D - Article from Alvaro A. Linero and David L. Read entitled, "Will the Hg Cycle Be Unbroken," which independently concludes that CBO technology is the best partner for the environment as mercury controls are implemented).
3. CBO greatly reduces the disposal of waste fly ash in landfills. Based on PMI's overall operating record with its first plant going into commercial operation in 1999, more than 5 million tons of fly ash have avoided being landfilled. Since the inception of PMI in the

late 1980's, using other solutions including a process to use fly ash in concrete block, more than 10 million tons of fly ash has avoided being landfilled.

4. Each of PMI's beneficiation processes provides approximately 180 temporary construction jobs and 44 permanent jobs to benefit the local economy.
5. PMI's beneficiation process reduces the fuel used at a cement plant when beneficiated fly ash is used as a partial substitute for Portland cement.
6. Each beneficiation process decreases the overall demand for Portland cement and the associated emissions from a cement kiln. While the United States has excess fly ash, fly ash recycling should be mandated in concrete which in turn reduces the need for additional cement kilns and the associated ambient air emissions.
7. PMI produces beneficiated fly ash, which is not only a lower cost raw material, but produces an end product that has superior qualities to end products made only with Portland cement.
8. CBO promotes sustainable economic development.

ii. EPA's proposed rulemaking to address CCRs will negatively impact SBAs if Subtitle C of RCRA is used

EPA has a rule proposed to address coal combustion residual (CCR) disposal and CCP recycling. The proposed rule has two co-proposals under Resource Conservation and Recovery Act (RCRA): a Subtitle C or hazardous waste approach and a Subtitle D or non-hazardous waste approach. The Subtitle C hazardous waste approach is so broad in scope that it will have direct adverse impacts on CCP recycling, which is the sole focus of our company.

We understand that EPA is concerned about the Subtitle D approach because EPA does not believe it has direct enforcement authority. To remove this potential road block, we strongly encourage members of this Committee to work to pass a law which gives EPA direct enforcement authority over CCRs, while continuing to manage fly ash under Subtitle D as a non-hazardous material. By ensuring that EPA has direct CCR enforcement authority, the Agency can follow its precedent, in that it approved the disposal of fly ash from the TVA Kinston spill in a Subtitle D landfill. In the TVA spill instance, EPA has direct oversight over the disposal of the fly ash under a Consent Decree. If EPA has approved a Subtitle D landfill as the ultimate disposal unit for ash from the TVA spill, it further demonstrates that Subtitle D is suitable and should be the choice as long as EPA can enforce national minimum standards.

My essential point today is that EPA's proposed Subtitle C option would be devastating to the still growing CCP beneficial use markets, and would slow economic growth and job creation in our fragile economy. EPA's attempt to create exemptions for beneficial use of CCPs under Subtitle C is not efficient or sustainable for small businesses. We have met with EPA and have advised EPA that we are not against increased regulations, but a Subtitle C scheme will be devastating for CCP beneficial use job growth for small businesses such as ours! Despite this

input from our industry, the Office of Management and Budget, state Departments of Transportation, the American Concrete Institute (ACI), and ASTM International stating the negative stigma and likely disallowance of fly ash as a recyclable product due to the Subtitle C "hazardous" classification, EPA continues to maintain that we are mistaken. EPA believes that a Subtitle C scheme will increase CCP recycling. EPA's position ignores the real world evidence from those involved in the CCP beneficial use markets. Again, we implore you to find the right regulatory solution by giving EPA direct enforcement authority under Subtitle D.

Our industry is already feeling the adverse impact merely from the threat of a Subtitle C hazardous waste program for CCRs. All the utilities we have spoken with have deferred their decisions to implement beneficiation technologies, such as our CBO solution. Our equipment requires significant investment and long term commitments in order to underwrite these investments. Our utility customers are unwilling to make such commitments, with the possible risk of tort liability related to the sale of a material that is otherwise classified as hazardous. In other CCP recycling markets, we have already seen negative ad campaigns warning customers against using CCPs, because they are hazardous wastes. Solutions such as ours bridge our energy future until more renewable sources of energy enter the market. It is a shame not to employ these solutions and create green jobs our economy needs today and will need into the future.

In addition, EPA does not and cannot control market standards like ASTM, ACI, and state DOTs. ASTM and ACI have clearly stated to EPA that they fear the "cradle to grave" liability that arises under RCRA Subtitle C and any related litigation will attach to downstream suppliers, architects, engineers and financiers in the product chain. They have stated that they will remove fly ash from their building specifications if EPA proceeds with the Subtitle C hazardous waste option for CCRs. In fact, we have already learned that the school system in Los Angeles, California has removed fly ash from their specifications (See Attachment E) and that the LEED green building classification that has encouraged fly ash recycling in concrete is considering disqualifying fly ash as a green material. All of these adverse impacts are directly attributable to EPA's proposed option of regulating CCRs under RCRA's hazardous waste program. These kinds of real threats prohibit utilities from starting beneficiation projects and lenders and investors from making funds available for projects. Result - no job growth! Further, we will see insurance costs and litigation risks increase unnecessarily to preserve existing business.

Furthermore, EPA actions discredit their own statements that they support fly ash recycling. Although EPA says in its proposed rulemaking that it favors beneficial uses which use fly ash in concrete; EPA's unilateral actions with regard to its C2P2 program – a program to grow the CCP beneficial recycling industry- have raised additional questions about its long term support of fly ash as a partial replacement for Portland cement. EPA closed its C2P2 website and suspended its support of the C2P2 program which has created additional uncertainty in the market place. In

the proposed regulations, EPA says it supports fly ash use in concrete, yet it has become alarmed that fly ash could be used in "consumer products", such as a filler in bowling balls. Their statement alone stigmatizes fly ash being used in fully encapsulated applications. These mixed signals ultimately inhibit our business and the jobs we create.

In summary, PMI firmly objects to any type of Subtitle C hazardous regulations for CCRs, and like other recycling partners can only support a Subtitle D non-hazardous regulatory program for these materials. This is because the Subtitle D regulatory option will not have the "unintended consequence" of negatively impacting CCP beneficial recycling. Any type of hazardous waste regulatory action will eliminate the nation's largest recycling success, fly ash as a partial replacement for Portland cement in concrete. We would support legislation which would specifically direct EPA to promulgate a CCR standard under Subtitle D and give the Agency direct enforcement authority, which the Agency via its actions at the Kinston site has already acknowledged would be protective of human health and the environment. I am hopeful that you or your colleagues will promptly introduce a bill to give EPA direction to develop regulations under Subtitle D of RCRA for CCRs and give EPA direct enforcement authority.

Attachment C

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENERGY & ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENVIRONMENTAL PROTECTION
ONE WINTER STREET, BOSTON, MA 02108 617-292-5500

DEVAL L. PATRICK
Governor

TIMOTHY P. MURRAY
Lieutenant Governor

IAN A. BOWLES
Secretary

LAURIE BURT
Commissioner

July 21, 2009

Re: 310 CMR 7.00 Appendix B(7)
Transmittal # X227555, X227556
Final Approval of BWP AQ 27 and AQ 28 Applications Certification and Verification of GHG Credits at Chesapeake, Virginia Carbon Burn-Out Plant

Attn: Kyle E. Crake
PMI Ash Technologies, LLC
14001 Weston Parkway, Suite 112
Cary, NC 27513

Dear Mr. Crake:

The Massachusetts Department of Environmental Protection (MassDEP) hereby approves your Application for Certification of GHG (Greenhouse Gas) Credits (BWP AQ27), dated March 30, 2009. The Department also approves your Application for Verification of GHG Credits (BWP AQ 28), dated March 30, 2009. In accordance with the requirements of 310 CMR 7.00: Appendix B(7)(f), the Department conducted a 30-day public comment period on the proposed approval and considered all comments received. The public comment period ended on July 20, 2009.

The Final Approval of your Application for Certification of GHG Credits (BWP AQ 27), combined with the Final Approval of your Application for Verification of GHG Credits (BWP AQ 28) creates 137,884 verified GHG Credits for emission reductions that occurred between January 1, 2007 and December 31, 2008. These credits have been deposited into MA GHG Credit account MAGHG-N-10011; the GHG Credit Account Representative for this account is Kyle Crake. Verified GHG Credits from this project can only be used by affected facilities for compliance with the CO_2 emissions standards of 310 CMR 7.29.

Included as part of this Final Approval of your Applications for Certification and Verification of GHG Credits are the following:

(1) A description of the project.
(2) A table showing the number of Certified and Verified GHG Credits.
(3) A list of relevant determinations that the Department has made in accordance with the requirements of 310 CMR 7.00: Appendix B(7).
(4) An explanation of how the number of GHG Credits was calculated.

Note that your applications are also incorporated, by reference, into this approval.

Attachment C

(1) Description of the Project

GHG Credits are awarded to the applicant, PMI Ash Technologies, LLC (PMI), for a project which processes coal ash at the Chesapeake Virginia Carbon Burn-Out (CBO) Plant for use in place of Portland cement in concrete manufacture. The number of GHG Credits is based on an estimate of the emissions that would have occurred if Portland cement were used instead of processed coal ash to manufacture concrete. The applicant has described the project as follows:

> *PMI Ash Technologies, LLC (PMI) has developed and installed a Carbon Burn Out (CBO) facility... The CBO facility is located at the Chesapeake Energy Center in Chesapeake, Virginia and went into commercial operation on November 1, 2006... The end product from... the CBO is a Coal Combustion Product (CCP) that is a low carbon fly ash used as a partial replacement for Portland cement in the production of concrete. The CBO in Virginia consists of one fluidized bed combustion system with a maximum heat input rating of 76.7 MMBtu/hr and is capable of processing up to 223,000 tons of fly ash per year. At this maximum production rate, approximately 204,000 tons of low carbon fly ash would be generated annually for use as a partial replacement to Portland cement in the production of concrete.*

(2) Table showing the number of Certified and Verified GHG Credits.

	Time period	Number of Credits
Certified GHG Credits	January 1, 2007 through December 31, 2008	137,884
Verified GHG Credits	January 1, 2007 through December 31, 2008	137,884

(3) A list of relevant determinations that the Department has made in accordance with the requirements of 310 CMR 7.00: Appendix B(7). (Defined terms and language that is directly excerpted from regulations appear in italics.)

The Department has made the following determinations:

- The emission reductions are *Real*, in that, when coal ash is used in place of cement, emissions that would have occurred during the manufacture of cement do not occur.
- The emission reductions are *Additional*, in that there is no legal requirement to process coal ash for use as a replacement for Portland cement, or to use processed coal ash as a replacement for Portland cement.
- The emission reductions are *Verifiable*, in that the applicant will provide documents showing the transfer of processed coal ash to Boral Material Technologies, Inc. (BMTI), an ash marketer with which the applicant has established a contractual relationship.

Attachment C

- The emission reductions are *Permanent*, in that once concrete has been manufactured using coal ash, the same concrete will never be manufactured using Portland cement.
- The emission reductions are *Enforceable*, in that, pursuant to 310 CMR 7.00: Appendix B(7)(g)8., violations of the requirements of 310 CMR 7.00: Appendix B(7) may be enforced against any person who applied for certification or verification of GHG Credits, an affected facility that purchases GHG Credits created by this project, or any combination thereof.
- The project commenced *on or after January 1, 2006*, in accordance with 310 CMR 7.00: Appendix B(7)(d)9, in that the ash processing facility commenced operation in November of 2006.
- The project is expected to *generate an annual average over the period applied for of 5,000 or more tons CO_2e*, in accordance with 310 CMR 7.00: Appendix B(7)(e)3, in that the project is expected to generate approximately 66,000 tons of CO_{2e} reductions annually.
- The application includes *a proposed method for determining, monitoring and assuring compliance*, in accordance with 310 CMR 7.00: Appendix B(7)(e)4.b, as described in section (4) of this document.
- The application specifies *the best management practice used to determine an emissions baseline*, in accordance with 310 CMR 7.00 B(7)(e)4.b, in that the project achieves greenhouse gas emissions reductions beyond those that would be achieved if current best management practice was employed. Supplemental application materials state:

  > *Installation and operation of a Carbon Burn Out process is not common practice at small power plant's which have installed pollution control devices that render the fly ash unsuitable for re-sale as a partial replacement for Portland cement. Because CBO is not required nor is it common practice at utilities, the BMP scenario allows Dominion Virginia Power at its Chesapeake Energy Station to have a consistent LOI <loss-on-ignition> and no ammonia from pollution controls it installed to reduce nitrogen oxides. The majority of utilities who have installed similar pollution control equipment or have altered operations to reduce nitrogen oxides do not employ active beneficiation CBO systems.*

  Note: Based on the conclusion that the project goes beyond current best management practice for processing and using fly ash to avoid greenhouse gas emissions from cement production, the department will allow the use of an emissions baseline based on historical practice at this facility to calculate avoided emissions.
- The project does not present any potential project leakage.

(4) Explanation of how the number of GHG Credits for Certification and Verification was calculated

The number of GHG Credits was calculated using the following equation:

GHG Credits = $N_{baseline} - N_{project}$

Where $N_{baseline} - N_{project}$ = the difference between the number of tons of CO_{2e} emitted without the project and the number of tons of CO_{2e} emitted by the project, calculated thus:

$N_{baseline} - N_{project} = A \times 0.71$

Where:

A = the number of tons of ash processed for use in place of Portland cement during the certification and verification period;

0.71 = an estimate of the number of tons of CO_{2e} emissions that are avoided when one ton of fly ash is used as a cement replacement, as proposed by the applicant. This estimate was derived by the United States Environmental Protection Agency (EPA) using the Building Environmental and Economic and Sustainability (BEES) methodology. The BEES methodology was used by EPA as the primary tool for calculating CO_{2e} emissions impacts in two reports that were published in 2008. (*See Waste and Materials-Flow Benchmark Sector Report: Beneficial Use of Secondary Materials – Coal Combustion Products* and *Study on Increasing the Usage of Recovered Mineral Components in Federally Funded Projects Involving Procurement of Cement or Concrete to Address the Safe, Accountable, Efficient Transportation Equity Act: A Legacy for Users*. In particular, Table D-13 in the latter source includes the numerical estimate used in this application. The document is available at http://www.epa.gov/epawaste/conserve/tools/cpg/pdf/rtc/report4-08.pdf and the table is on page D-41.)[1]

[1] MassDEP is using the BEES model in order ensure that the number of GHG Credits created represents a conservative estimate of the actual reductions that occurred. The BEES model is not the only model that could be used to estimate number of tons of CO_{2e} emissions that are avoided when one ton of fly ash is used as a cement replacement. However, MassDEP has concluded that the difference between the available estimates is associated with uncertainty, and therefore does not imply that one estimate is more correct than another. Using the more conservative of these estimates (i.e., the lower of the estimates, which is associated with the BEES model) provides greater certainty that all estimated avoided emissions have actually occurred. Further information regarding MassDEP's decision to use the BEES model for this purpose is contained in MassDEP's Conditional Approval of a similar certification application that was submitted by Dominion Energy Brayton Point, and in the associated Response to Public Comment. These documents are available at http://www.mass.gov/dep/air/climate/ghgcred.htm.

Attachment C

GHG CREDIT CERTIFICATION AND VERIFICATION
PMI Ash Technologies, LLC
Transmittal # X227555, X227556 Page 5 of 5

Data and calculations for this application are summarized in the following table:

A	194,203
Certified and Verified GHG Credits	**137,884**

Should you have any questions concerning this FINAL APPROVAL, please contact Stacy DeGabriele at stacy.h.degabriele@state.ma.us or (617) 292-5864.

Very truly yours,

Nancy L. Seidman
Deputy Assistant Commissioner
Climate Strategies
Bureau of Waste Prevention

cc: William Lamkin, DEP, BWP, NERO
William Spacc, DEP, BWP, Boston
Stacy DeGabriele, DEP, BWP, Boston
Loreen Kelley, DEP, BWP, Boston

Will the Hg Cycle be Unbroken? An Air and a Waste Management Issue!

Paper # 658

Alvaro A. Linero and David L. Read
Florida Department of Environmental Protection, 2600 Blairstone Road, Mail Station 5505, Tallahassee, Florida 32399

ABSTRACT

The Clean Air Interstate Rule (CAIR) requires additional reductions of acid rain precursors (NO_X and SO_2) from power plants in the eastern United States. The recently vacated Clean Air Mercury Rule (CAMR) required nation-wide reductions of mercury (Hg) from coal-fueled plants and in the initial phase relied largely on NO_X and SO_2 control techniques in combination to effect reductions of Hg.[1,2] Regardless of the current uncertainty of federal regulations for the reduction of Hg emissions from coal-fueled power plants, it is safe to assume that Hg emissions reductions from such sources will be required in the future. Further, the latest cement industry Maximum Achievable Control Technology (Cement-MACT) did not regulate Hg from existing cement kilns and is under litigation and reconsideration.[3,4] Consequently, this review demonstrates that a significant amount of Hg removed from coal-fueled power plants can be re-emitted from existing cement kilns that use fly ash from CAIR-regulated coal-fueled plants as a raw material. The conclusion is that to achieve effective Hg reduction, the U.S. Environmental Protection Agency (EPA) must adopt a multi-media and multi-industry approach when it reissues its Hg rules for the power and the cement industries and in any rules governing the disposal or reuse of coal combustion byproducts (CCP).

MERCURY IN COAL

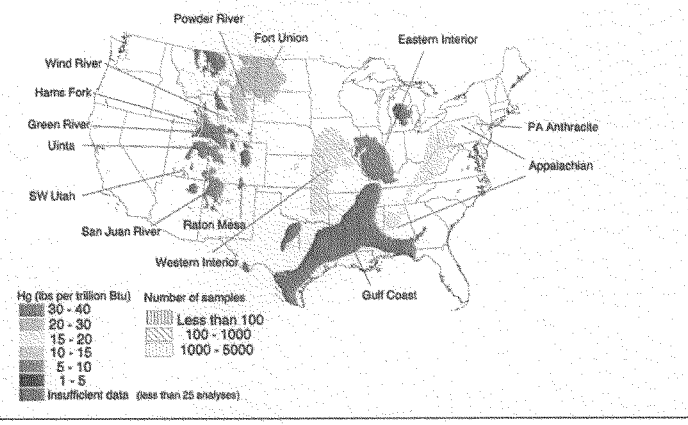
Hg is present in coal and is typically expressed in terms of parts per million by weight (ppm). The following table is a listing of the average Hg concentration for several coal classifications. Values are also given in terms of pounds per trillion Btu of heat input (lb/10^{12} Btu).[5] The values in Table 1 are representative of coal in the ground but not necessarily of coal mined or used.

Table 1. Hg in Various Coals Ranks and Types.

Coal Field	Hg (ppm, average)	Hg (lb/10^{12} Btu)
Appalachian	0.20	15.4
Eastern Interior	0.10	8.2
Gulf Coast	0.22	36.4
Powder River	0.10	12.6
Fort Union	0.13	21.8

Figure 1 is a graphical representation of Hg distribution throughout the key coal provinces of the United States (U.S.). Again, the distribution does not necessarily relate to how specific coal supplies are actually mined because of factors such as depth, quality, environment, etc.

Figure 1. Hg Concentration in Coal on a lb/10^{12} Btu Basis (Source USGS).



At the request of the Florida Department of Environmental Protection (DEP) Hg values were provided by operators for coal-fueled Power Plants A and B referenced in discussions further below. The average Hg concentrations in the composite coal samples collected from two units at Power Plant A were 0.039 and 0.054 ppm. The average Hg concentrations in the composite coal samples collected from the four units at Power Plant B were between 0.065 and 0.076 ppm.

EMISSIONS FROM THE COAL-FUELED POWER INDUSTRY

According to the Department of Energy, the electric power sector used a little more than 1 billion (bn) tons of coal in 2006.[6] Assuming an approximately 0.10 ppm of Hg in the coal actually used, the uncontrolled emissions can be on the order of 100 tons per year from the power industry.

According to the U.S. Environmental Protection Agency (EPA), aapproximately 75 tons of Hg are in the coal delivered to power plants each year.[7] That implies that the average Hg concentration in the coal actually used is approximately 0.075 ppm or a little greater than the measurement at Power Plant B. About 48 tons or nearly two thirds of the Hg are emitted annually from coal-fueled power plant in the U.S. According to EPA, the 27 ton reduction is achieved in the power plant boilers and through existing pollution controls for particulate matter (PM), SO_2 and NO_X.

EMISSIONS REDUCTIONS PREVIOUSLY REQUIRED BY CAMR

Before the rule was vacated, CAMR required reductions from 48 to 38 tons of Hg from the total of all coal-fueled power plants by 2010 and to 15 tons by 2018. Allocations to each state were made by EPA on the basis of unit-by-unit determinations. Provisions were made for a national cap and trade program similar to the existing one under the Acid Rain Program. The allocation to units in Florida is listed in Table 2. Florida's allocation was 0.487 tons or 973 pounds (lb).[8]

Table 2. Final 2018 Hg Allocations in lb/year by the CAMR to Coal-Fueled Units in Florida

Facility	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Total
Cedar Bay	8	8	8					24
Central Power & Lime	11							11
GRU Deerhaven		18						18
Gulf Lansing Smith	15	17						32
Gulf Plant Crist				5	6	20	40	71
Gulf Scholz	2	3						5
Indiantown Cogen	19							19
JEA Northside	12	15						27
JEA St. Johns River	**64**	60						124
Lakeland McIntosh			34					34
OUC Stanton Energy	37	36						73
Progress Crystal River	27	39		61	62			**189**
Seminole Palatka	60	61						121
TECO Big Bend	31	32	29	40				132
TECO Gannon	8	8	11	13	14	24		78
TECO Polk Power	15							15
Total								**973**

For reference, the largest allocation based on EPA's estimate for a single power plant in Florida was 189 pounds of Hg per year (lb Hg/yr) or approximately 0.095 tons per year (TPY). The coal-fueled units that comprise the plant are rated at approximately 2,300 MW (total). The largest allocation to a single unit was 64 lb/yr for a 650 MW unit.

As a point of reference, until the early 1990's the threshold for determining whether a new project was subject to the Rules for the Prevention of Significant Deterioration (PSD) and a best available control technology (BACT) determination was 200 lb Hg/yr. EPA removed that threshold from its PSD rules. However, Florida still adheres to it.

EMISSION CONTROLS FOR COAL-FUELED POWER PLANTS

The previously required reduction under Phase II of CAMR was on the order of 70 percent (%) from present emissions levels. To control NO_X and SO_2 emissions and meet CAIR requirements, coal-fueled power plants use various emission control technologies. Some of these effect collateral reductions in Hg. A brief summary of these control technologies is given below and depicted in Figure 2.

- Low NOx Burner (LNB)/Over Fired Air (OFA) – LNB use modified air and fuel entry to slow the mixing rate, reduce the oxygen available for NO_X formation in critical NO_X formation zones, and/or reduce the amount of fuel burned at peak flame temperatures. OFA is a staged combustion technique where all burners are operated in a fuel rich mode, with additional combustion air supplied through special overfire ports.
- Selective Catalytic Reduction (SCR) – Ammonia reacts with NO_X on a catalyst to reduce NO_X to N_2. Selective Non-Catalytic Reduction (SNCR) also uses ammonia to reduce NO_X but requires higher temperature and does not use a catalyst.

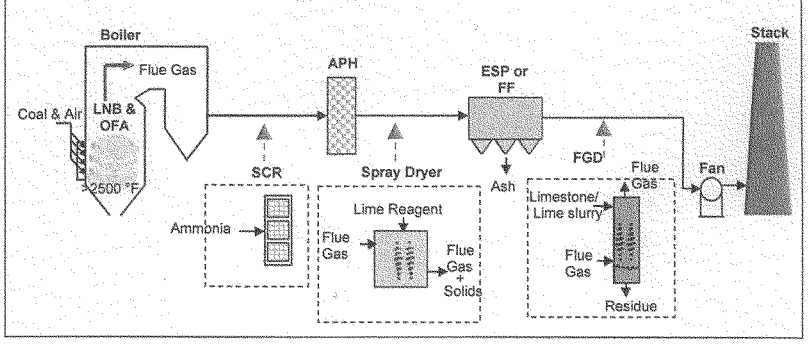
- Spray Dryer Absorber (SDA) – Flue gas is contacted with a lime reagent in an absorber vessel where SO_2 reacts to form calcium sulfate and calcium sulfate salts, which are then removed with the fly ash in the downstream PM control device.
- Electrostatic Precipitator (ESP) – An electrical discharge charges fly ash particles in the flue gas stream which are then collected on collection plates.
- Fabric Filter (FF) – Typically in lieu of an ESP Flue gas passes through a bag made of tightly woven fabric, where the PM is collected on and within the fabric.
- Wet Flue Gas Desulfurization (FGD) – Typically in lieu of a SDA. Flue gas contacts limestone or lime slurry where the SO_2 reacts to form calcium sulfate/calcium sulfite salts and in some cases this waste stream is further oxidized to form a gypsum byproduct.

For many coal-fired plants, the required Hg reduction can be effected by the controls for CAIR. Hg removal can be enhanced by treatment of the coal and other measures in the pollution control equipment. Also sorbents such as activated carbon can be injected (ACI) that attract Hg can be injected before the PM control device thus removing most Hg with other fly ash. Alternatively ACI can be practiced after the main PM control device with removal as a smaller fly ash stream in a separate PM control device.

The mechanisms of Hg capture in coal-fired power plants are very complicated. The reader is referred to the many EPA CAMR technical background documents available at www.epa.gov/ttn/atw/utility/utiltoxpg.html . They can be summarized as:

- Adsorption of Hg by injecting a sorbent, such as ACI, or onto the unburnt carbon in high loss on ignition (LOI) fly ash, particularly when LNB and OFA are employed;
- Oxidation of Hg across the SCR catalyst, thus making Hg more collectable in downstream pollution control equipment;
- Collection of particulate Hg and fly ash in the ESP and FF PM control devices; and
- Capture in other streams such as wet FGD scrubbers.

Figure 2. Emission Control Technologies for Coal-Fueled Power Plants.



It is immediately apparent that the short term fate of the captured Hg is in and with the coal combustion byproducts (CCP) such as fly ash and gypsum. That is the focus of this paper.

The CAMR would have permitted new bituminous coal-fueled units within the national cap, but required them to comply with a limit of $20x10^{-6}$ lb Hg/MW-Hour (lb/MWH). The emission factor seems unreasonable considering that the pool of data collected from existing "well controlled" bituminous units from which the emission limit was derived ranged only from 1.1 to $3.6x10^{-6}$ lb/MWH. Furthermore some of the units in the data pool did not have SCR equipment. Some relied on wet scrubbers instead of fabric filters. None of them practiced sorbent injection such as ACI described above. Finally, the data were renormalized to assume that all new plants will use relatively high Hg coal.

The pyramiding of these assumptions resulted in an emission limit disconnected from the realities of what is possible for a new project considering the control options actually available to those projects. One of the authors provided comments to the EPA docket about the new limit prior to finalization of CAMR.[9]

Therefore a new 2,300 MW bituminous coal-fueled plant (equal in capacity to the largest existing plant in Florida) operating at a 90% capacity factor would have been limited to 363 lb. That is almost twice the allowance of the previously mentioned large plant.

CCP UTILIZATION

Ideally fly ash can be used directly in various types of concrete and the resulting products are often stronger and longer lasting[10]. Numerous studies have been conducted by the testing arms of PCA and the concrete associations that attest to this observation.

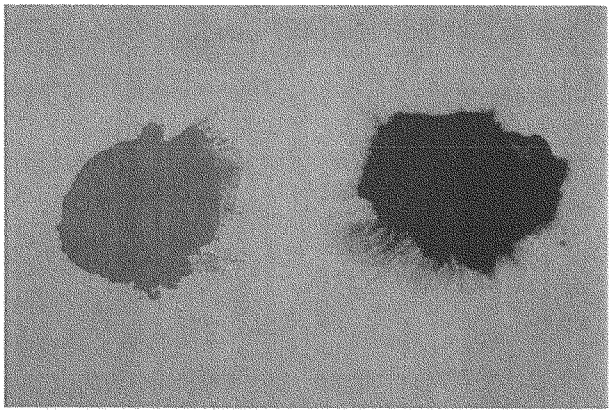
Similarly efforts have been aimed at showing that products such as gypsum wallboard and concretes that use CCP retain to a large extent the contained metals such as Hg[11]. The reader is referred to the following University of Kentucky website for the relevant papers given by international experts on beneficial utilization of CCP: www.flyash.org . The ideal situation is immobilization of Hg in the ultimate products made from CCP.

It has been recognized for several years that the principle control technologies for NO_X control affect fly ash and can render it less usable in concrete[12,13]. The reasons in summary are: high LOI caused by reducing conditions in the furnace or insufficient burnout time; and high ammonia (NH_3) from the SCR/SNCR system. There are a number of fly ash remediation processes.

One such process involves the combustion or burnout of the carbon fraction of the high LOI fly ash in a heated circulating fluidized bed followed by cooling of the gases and products and fabric filtration. The photograph in Figure 3 shows the darker high LOI feed stream on the right and the grayish concrete-quality low LOI product on the left. As discussed further below, the Hg present in the incoming feed stream follows the remediated concrete quality product.

Other remediation processes include one whereby the high LOI fly ash is subjected to a separation process that yields a low LOI concrete-quality product much like the material in the left hand side of the above photograph. It also yields a smaller stream that is darker than and exhibits greater LOI properties than the incoming feed stream. The very high LOI product can contain significant concentrations of Hg. The ramifications of the remediation processes are discussed further below.

Figure 3. Picture of Remediated Low LOI Product and of High LOI Feed.



CASE STUDY – FOUR COAL-FUELED POWER PLANTS

Description

Four coal-fueled power plants in the southeast U.S., including two in Florida, were assessed for the Hg concentrations in various process streams with particular focus on the amount contained in the fly ash. Three of the plants have fly ash remediation equipment. The process streams for each plant that were measured for Hg concentration are outlined below. Table 3 summarizes the number of power units, power rating, coal type, and pollution controls used at each plant.

- Plant A – Hg concentrations were measured in the coal, gypsum from the FGD, fly ash and bottom ash. Hg concentrations were also measured in the fly ash streams prior to and after separation of high and low LOI fractions.
- Plant B – Hg concentrations were measured from the coal, fly ash, and bottom ash. Two of the units (designated as 1 and 2 in this review) have both hot side (HS) ESPs located before the air preheater (APH) and cold side (CS) ESPs located after the APH. The other two units (designated as 3 and 4 in this review) have only CS ESPs. None of the units have fly ash remediation systems and all fly ash is presently landfilled.
- Plant C – Hg concentrations were measured in both the ESP fly ash and in the single remediated concrete-quality product. No concurrent measurements were made for the coal and other CCP.
- Plant D – Hg concentrations were measured in both the ESP fly ash and in the single remediated concrete-quality product. No concurrent measurements were made for the coal and other CCP.

Table 3 is a summary of the capacities, coal type and pollution control equipment for Plants A, B, C and D.

Table 3. Summary of Case Study Power Plants.

Plant	Unit	Power (MW)	Coal Type*	NO_x Control	PM Control	SO_2 Control
Plant A	1	1260	Eastern Bituminous	LNB	CS ESP	FGD
	2					
Plant B	1	984	Eastern Bituminous	LNB/SNCR	HS & CS ESP	Low Sulfur Coal
	2			LNB/SNCR	HS & CS ESP	
	3			LNB/SNCR	CS ESP	
	4			LNB/SCR	CS ESP	
Plant C	1	700	Eastern Bituminous	LNB/SCR	FF	N/A
	2					
Plant D	1	1,155	Kentucky Bituminous	LNB/SCR	CS ESP	N/A
	2					FGD
	3					
	4					

* Primary Fuel. For example Plant A typically co-fires petcoke, but not during the test program.

Results

Test results of Hg concentrations from most of the process streams for each case study power plant are presented in Table 4.

Table 4. Summary of Hg Concentration Results for Case Study Power Plants.

			Average Hg Concentration (ppm)						
			Power Plant Streams				Remediation Process		
Plant	Collection Duration	Unit	Coal	Fly Ash		Gypsum	Input	Low LOI Product	Higher LOI "Fuel" Product
				Hg	%LOI				
A	5 days	1	0.039	0.151	~16%	0.259	0.223	0.034	0.752
		2	0.054	0.107		0.342	0.150	0.026	0.735
B	7 days	1 HS	0.069	0.038	~10%	No FGD	No Remediation System		
		1 CS		4.67	~6%				
		2 HS	0.071	0.007	~10%	No FGD	No Remediation System		
		2 CS		2.22	~4%				
		3	0.065	0.850	~20%	No FGD	No Remediation System		
		4	0.076	0.456	~10%	No FGD	No Remediation System		
C	7 Days	1-2	No measurements taken				0.49	0.55(5)	No High LOI Product
D	4 Days	1-4					0.47	0.79	

Some of the data are under request and other data are still under review. It is not a simple matter to design an experiment and actually obtain requested data on a voluntary basis. Typical flow

rates are still needed to conduct more quantitative analyses of the Hg mass flows. What was obtained generally depended on the willingness of the given operators, licensors and licensees. The data still suffice to confirm some hypotheses and to suggest a few other trends.

- The combination of LNB and SCR technologies on Plant B, Units 3 and 4 cause enrichment of Hg into the fly ash by a factor of 6 to 12. The greater concentration in the fly ash from Unit 3 relates well to the much greater LOI characteristic of fly ash from Unit 4. The resulting fly undoubtedly contains most of the Hg contained in the original coal used at Plant B.
- The LNB technology on Plant A caused enrichment of Hg into the fly ash by a factor of 2 to 4. The fly ash contains a significant portion of the Hg while the wet scrubbers also remove a significant amount of the fly ash. Construction has commenced on SCR systems that may promote further Hg enrichment into the fly ash or collection in the scrubbers.
- The remediation process used at Plant A produces concrete quality fly ash with Hg concentrations roughly in the same order of magnitude compared with the coal used. A separate and smaller high LOI "fuel quality" (roughly 46% LOI) stream is also produced that is greatly enriched in Hg. The enrichment factor is between 15 and 20.
- The remediation process used at Plants C and D produces only concrete quality fly ash that appears to contain virtually all of the Hg introduce into the remediation process. The differences between input and product Hg concentrations are due to burnout of most the LOI fraction (excess carbon) and resulting smaller product mass. The Hg levels into the process are consistent with the recent air pollution control projects at Plants C and D such as SCR.

The Hg enrichment of the fly ash from units using LNB has been previously documented. For example, according to an Electric Power Research Institute (EPRI) report entitled "Mercury Control via Combustion Modifications at Duke Energy" it was shown that "Hg removals greater than 50% appear achievable at LOI levels greater that 10%" and "removals ~90% across an ESP were observed at LOIs>20%."[14]

Although previously documented, it is important to demonstrate the enrichment phenomenon again in a single paper aimed at both the power and cement industries.

AVAILABILITY OF FLY ASH FOR USE IN CEMENT PYROPROCESSING

Few power plants presently practice fly ash remediation. Much of the available fly ash is nevertheless useful as concrete quality fly ash. As the amount of quality of unremediated fly ash useful for concrete declines, more becomes available for other uses if not disposal.

The concept of using unremediated high LOI fly ash as a raw material and fuel component in cement plants has been in practice for several years at certain facilities. The idea is further supported by data in a recent paper showing that the "cement produced during the demonstration was comparable to normally produced cement in chemical and physical properties".[15] The paper further concludes that "using 6 percent fly ash in U.S. cement manufacturing, can consume more than 9 million tons of fly ash annually. The demonstrations signal the emergence of a new market for *unusable* high-carbon (LOI) fly ash with tangible material, operational, product, and environmental benefits to both the power generation and cement industries.

The authors of the present paper do not dispute those conclusions. However, the possible unintended ramifications of this scenario, with regard to increased Hg emissions from cement kiln or other processes, require further examination, which is the purpose of this paper.

CEMENT PLANTS

Process

In modern dry process preheater/calciner (PH/C) cement plants, every effort is made to turn all raw materials into product with no waste. The final dust control device, usually a FF, is part of the process equipment. The dust is actually considered as feed and is returned to the process.

Figure 4 was developed from a diagram in a European Cement Bureau (CEMBUREAU) report. The circuit shown in red represents volatile species such as Hg that enter primarily with the raw materials, including high LOI fly ash, via the raw mill. The raw mix entering the raw mill is intimately contacted with exhaust gases traversing the kiln, calciner and preheater.

Figure 4. Internal and External Circulations in a Cement Kiln and Possible Hg Bypass Stream.

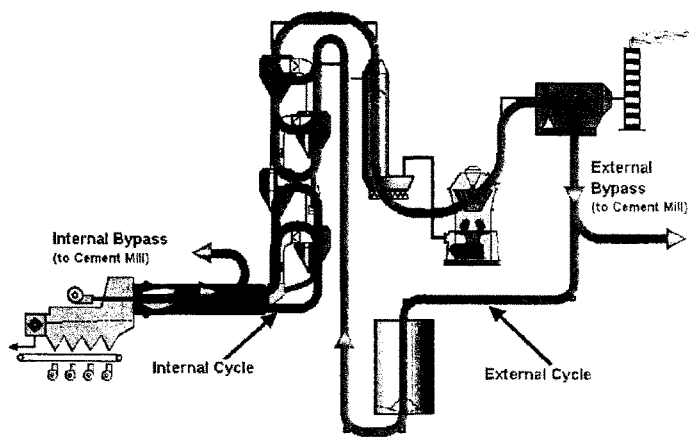


Figure 4 was developed from a diagram in a European Cement Bureau (CEMBUREAU) report. The circuit shown in red represents volatile species such as Hg that enter primarily with the raw materials, including high LOI fly ash, via the raw mill. The raw mix entering the raw mill is intimately contacted with exhaust gases traversing the kiln, calciner and preheater.

That raw mix is ground and actually adsorbs additional Hg from the exhaust gases, some of which is also of fuel origin from the internal cycle (blue circuit). The concentration of Hg builds up in the red circuit until the amount entering via the raw materials and fuel equals the amount that exits the stack. If the raw mill is turned off and the process continues using raw meal from

the feed silo, a great portion of the Hg trapped in the red circuit is released until the raw mill is restarted.

It is unrealistic to expect that any Hg will leave via the clinker because it will be vaporized long before reaching the kiln exit. This fact was demonstrated in a study conducted at the NORCEM facility in Brevik, Norway by use of radioactive Hg203 as a tracer.[16]

Unless additional air pollution control equipment is used, the only reasonable mitigation is by the purposeful withdrawal of a portion of the dust from the dust control equipment. Such dust can be wasted or combined with clinker at the cement finishing mill. The practice can be combined with the operation of the dust control equipment at lower temperature during the time that the raw mill is down. This reduces the Hg vapor pressure and hence emission. Some process modeling and Hg sampling is necessary on a kiln-by-kiln basis. The efficacy of this method has been claimed for European cement plants.[17]

There is resistance to this step in the cement industry because it either wastes material or brings into question the acceptability of the product cement within the specification of Type I cement in accordance with the standards of the American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM). Such concerns may cause the cement to be rejected by state Department of Transportation (DOT) agencies. These concerns are not as acute in Europe.

High LOI Fly Ash and Hg Emissions

Without such dust removal or another techniques to reduce Hg, the use of fly ash from power plants with high LOI and Hg concentrations in the pryroprocessing portion of a cement kiln is contraindicated. It is no different in principle than using in cement kilns the fly ash from power plants that employ activated carbon injection (ACI) for Hg reduction, a practice that is partially restricted by present EPA regulations.

To quickly illustrate the concern of the authors the following hypothetical scenario is presented. Assume that a 2,400 tons per day cement plant will use only 100 tons per day (TPD) of the either high LOI "fuel product" from the Plant A remediation process or just the straight fly ash from Plant B. The average concentration in those streams is 0.70 ppm Hg. Assuming 95% annual cement availability, emissions accountable by use of high LOI fly ash alone will be on the order of 50 lb/yr. This value that does not include the contributions from the other raw materials and fuel used at the is equal to the ultimate future allocation for a moderately large coal-fueled power unit.

Case Study

A cement plant in the southeast is used to illustrate the problem described in the preceding paragraph in real-world terms. Plant data on material feed rate and Hg emission are available from calendar years 2005 to 2007. This plant is permitted to process roughly 1,000,000 TPY of raw feed consisting primarily of limestone, sand, iron ore, fly ash, and high LOI fly ash. The high LOI fly ash is identified as high carbon fly ash (HCFH).

The total monthly feed rates into the preheater/calciner along with the monthly composition of these feed materials, including percentages where applicable, during calendar year 2007 are given in Table 5. The coal/Petcoke fuel feed rate in tons per month is also presented in the table. This year is typical for plant operations. However, the feed rate of HCFA varies from roughly 1 percent to nearly 5 percent during calendar years 2005 to 2007.

HCFA was not used during the first four months of 2005. The variation in the HCFA feed rate was dependent upon how near the plant was to its Hg emission limit of approximately 97 pounds per year, based on a rolling 12-month average. The nearer the plant was to rolling average limit the less HCFA was fed into the PH/C to reduce Hg emissions.

Table 5. Monthly Feed Rate to Cement Kiln, Year 2007.

Yr 2007	Total	Feed, Tons (% of Feed)				High LOI Ash	Fuel
Month	Feed (Tons)	Limestone	Sand	Iron Ore	Low LOI Ash	Tons	Tons
Jan	75,294	62,042 (82.4)	4,442 (5.90)	1,280 (1.70)	7,454 (9.90)	1,535	5,568
Feb	101,510	86,923 (85.6)	5,235 (5.16)	1,239 (1.22)	8,122 (7.99)	3,357	6,357
Mar	115,081	98,716 (85.8)	5,713 (4.96)	1,269 (1.10)	9,383 (8.15)	4,254	7,211
Apr	117,539	99,791 (84.9)	5,407 (4.60)	1,410 (2.20)	10,814 (9.20)	4,184	7,345
May	126,279	109,700 (86.9)	7,016 (5.56)	1,585 (1.26)	7,978 (6.32)	4,871	7,501
Jun	112,140	91,747 (81.1)	8,807 (7.85)	1,429 (1.27)	10,157 (9.06)	3,691	7,407
Jul	85,789	73,543 (85.7)	4,981 (5.81)	1,199 (1.40)	6,066 (7.07)	2,171	5,463
Aug	114,510	97,471 (85.1)	6,477 (5.66)	1,422 (1.24)	9,121 (7.97)	4,072	7,164
Sep	114,510	97,471 (85.1)	6,477 (5.66)	1,422 (1.24)	9,121 (7.97)	4,072	7,164
Oct	135,867	119,563 (88)	5,633 (4.15)	1,661 (1.22)	9,909 (6.63)	3,163	9,976
Nov	111,335	94,724 (85.1)	5,723 (5.14)	1,314 (1.18)	9,575 (8.60)	2,353	7,016
Dec	103,655	87,248 (84.2)	4,301(4.15)	976 (0.94)	11,130 (10.74)	2,460	6,823

The Hg concentration (ppm) in the HCFA is shown in Figure 5. As seen in the figure, initially the Hg concentration in the HCFA was less than 0.1 ppm, but then increased. It was then consistently greater than 0.2 ppm for most of calendar year 2007. The Hg concentration was the greatest (0.37 ppm) in January and February of 2007.

Figure 5. Monthly Hg Concentration in HCFA.

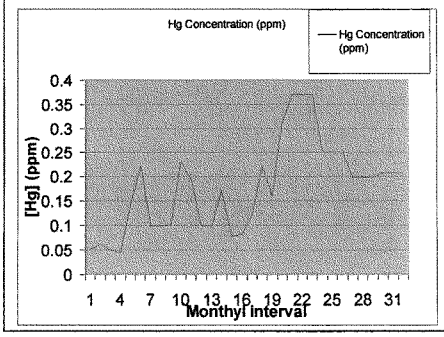
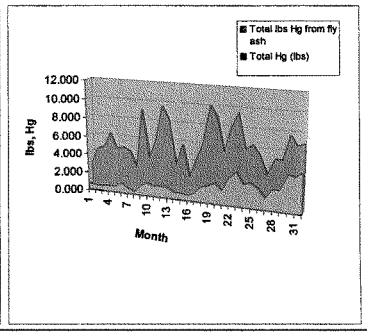


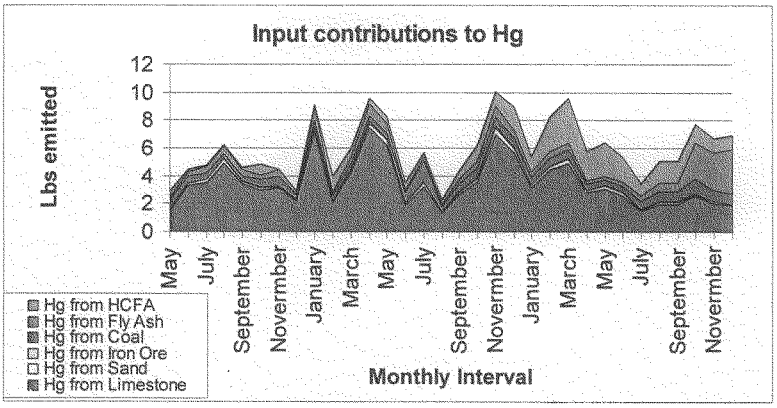
Figure6. Monthly Fly Ash Mass Hg input .



The contributions of the fly ash to the overall Hg inputs to the plant (equal to emissions) are shown in Figure 6. In this figure the total monthly Hg inputs to the plant (equal to emissions) are shown along with the contribution from total fly ash (both low and high LOI). As is seen in the figure, once the Hg concentration in the fly ash began to increase during calendar 2007, the percentage contribution from fly ash to the total Hg emissions increased significantly. The feed of fly ash, particularly the HCFA was adjusted to keep Hg emissions below permitted limits.

Finally, Figure 7 shows the contribution to monthly Hg emissions from May 2005 to December 2007 from all feed materials (limestone, sand, iron ore, fly ash, HCFA, and coal). In many months the fly ash (whether or not classified as HCFA) was the greatest contributor to Hg emissions, especially in Calendar year 2007.

Figure 7. Feed Material Contributions to Monthly Hg Emissions. Mid-2006 through 2007.



In summary, this case study illustrates that HCFA can be a major contributor of Hg emission from a cement plant. Regulators and the industry, both power and cement, must be educated about this possibility, especially as pollution control equipment associated with CAIR come online at coal-fueled power plants and as a replacement for the CAMR comes into force

Cement Plant Regulations

EPA did not establish Hg emission limits from existing cement plants in the latest version of 40 CFR 63, Subpart LLL - National Emission Standards for Hazardous Air Pollutants From the Portland Cement Manufacturing Industry (December 20, 2006). Few cement plants in the U.S. have Hg permit limits and those that do, typically have relatively high allowable emissions (100 – 225 lb/yr) by present day considerations. Contrast these values with the expected 5 lb Hg/yr from a very well-controlled coal-fueled unit or even the seemingly high 2018 allocations from units previously subject to the now vacated CAMR.

Operators of such cement kilns might typically operate at levels about half of their allowed emissions and believe they are doing quite well. They may also believe that they are well within their rights to take Hg-laden fly ash from the power plants as long as their own emissions are

within the permitted cement plant limits even though the Hg removed by power plants is re-emitted.

EPA was sued by the PCA because of the Hg limits established for new kilns and by several states and environmental groups for the lack of limits on existing ones.

Cement Plant Control Techniques

With respect to cement plants, this paper only addressed the phenomenon of impacts from power plant fly ash and how to bleed off Hg by withdrawing dust from cement particulate control equipment and recombining that dust with product. The details of alternative controls are beyond the scope of the present paper and should be followed up by other investigators.

However, some of the same technologies such as ACI and FGD are actively under consideration within the ongoing rule writing by EPA. It may even be possible that there is a role for SCR in conjunction with other technologies to maximize the amount of Hg collected. EPA previously invited comment regarding a possible fly ash ban. That should be considered only in the event that the present rulemaking efforts continue to be stalemated.

FUTURE DEVELOPMENTS

Following the action to vacate the Federal Court action to vacate the CAMR, it is possible that the holes in the power plant rule (Subpart Da) and the cement rule (Subpart LLL) will be plugged.

If a cooperative effort can be quickly launched between the cement companies, the state Departments of Transportation, EPA, and, ideally, the CCP dealers, a situation can be avoided that may result in the removal of a substantial amount of fly ash from the CCP market.

The scenario citing the use of the high LOI fly ash from a remediation process in a cement kiln is the extreme. However, the same phenomena can occur to some extent for all fly ash not directly usable as a CCP if no control is employed by the cement plant. The case in point is that of a cement plant in Michigan that is known to re-emit a significant amount of Hg removed via fly ash from a power plant in Ontario.

Both the cement industry and the power industry have been slow to recognize and deal with this matter. This is not surprising given the expectation that these phenomena would have been recognized and addressed in federal rulemaking on a multi-media and cross-industry basis. Additionally the manner by which new information is considered is hampered by the legal process in rulemaking, especially once rules have been challenged. Finally, there are inherent difficulties in trying to achieve consensus among members of trade associations.

One interesting development is the plan by Ash Grove Cement to install an ACI system at a 1 ton per year Hg source in Oregon.[18] In that case, the source of the Hg is the native limestone. This will focus attention as to the actual possibilities of controlling such sources and could theoretically be extended for use at cement plants that use high LOI fly ash or even sewage sludge.

Finally, some of these issues may finally be recognized in the ongoing rulemaking by EPA related to fly ash disposal. The authors have alerted EPA's responsible engineers on that project. In the meantime, the Florida Department of Environmental Protection is proceeding with its own rulemaking to reduce emissions from industries that emit large amounts of Hg. Among the reasons is that EPA is requiring the Department to remove Hg as a pollutant subject to regulation under its federally approved PSD program.

CONCLUSIONS

This review demonstrates that Hg removed by attempts to comply with the CAIR and the (now vacated) CAMR can lead to a deterioration of power plant fly ash making it less useful for concrete though still useful in pyroprocessing. The result can be the emission of more Hg of power plant origin via cement pyroprocessing than from the power plants.

Fly ash remediation processes and purposeful dust withdrawal at cement plants and blending into the product can help shepherd Hg to concrete, although certain "fuel" products from fly ash remediation can aggravate cement plant emissions.

Both the cement industry and the power industry have been slow to recognize and deal with this matters. This is not surprising given the expectation that these phenomena would have been recognized and addressed in federal rulemaking on a multi-media and cross-industry basis. Additionally the manner by which new information is considered is hampered by the legal process in rulemaking, especially once rules have been challenged. Finally, there are inherent difficulties in trying to achieve consensus among members of trade associations.

ACKNOWLEDGEMENTS

The authors acknowledge the encouragement and support of their employer, the Florida Department of Environmental Protection and of the chemists at the Department's Bureau of Laboratories. The authors also acknowledge the efforts of certain cement operators that routinely collect and report Hg input to pyroprocessing as well as the assistance of certain power plant operators who provided fly ash or coal Hg and LOI data.

KEY WORDS

Cement, Coal, Power Plants, MACT, Mercury, Hg, NO_X, SO_2, Fly Ash, LOI, CAIR, CAMR

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Attachment E

DESIGN PROCEDURE CLARIFICATION No. 154
LOS ANGELES UNIFIED SCHOOL DISTRICT

TO: Design Management Team **DATE:** April 27, 2010

FROM: Vincent Coffeen, Design Management Director VC 4.28.10

SUBJECT: Stop Usage of Fly Ash in LAUSD Projects

Background:

LAUSD is committed to sustainable or "high performance" design in all of its schools. A well-designed high performance school enhances student and teacher performance, reduces operating costs, and protects the environment. The LAUSD Board of Education recognized these advantages in its October 2003 High Performance Schools Resolution. The Resolution directs staff to **"continue its effort to ensure that every District new school and modernization project, from the beginning of the design process, incorporate high performance school criteria to the extent feasible."**

The District endorses the high performance school strategies defined in the Collaborative for High Performance School (CHPS) Best Practices Manuals, in particular "Volume II, Design," and "Volume III, Criteria"; which calls for the use of environmentally preferable materials that are durable, healthy, made with recycled content, salvaged or reused, recyclable, sustainable products, environmentally benign, made with industrial byproducts, market in an environmentally responsible manner.

In an effort to comply with the Board's October 2003 resolution the District Guidelines and technical specification section 03300 – Cast in Place Concrete were revised to include ASTM C618 - Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, and ASTM C989 - Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars as part of this section. Section 03300, Article 2.01.D.5 encourages the use of fly ash and blast-furnace slag to reduce the impact of cement manufacture, and requires the Design Professional to "Determine if the use of fly ash and blast-furnace slag is acceptable, available at a competitive price, and would not result in inadequate bid competition."

The collapse of an earthen retaining wall of a containment structure at the Tennessee Valley Authority's Kingston, Tenn., coal plant[1] in December 22, 2008 prompted the EPA to reconsider its original ruling about the toxicity, and adverse effects of fly ash on human health and the environment.

Present Conditions:

The Environmental Protection Agency (EPA) is considering reclassifying fly ash as a hazardous waste under Subtitle C of the Resource Conservation and Recovery act[2]

The Leadership in Energy and Environmental Design (LEED) rating system encourages the use Fly Ash, and currently considers it as a post industrial recycled material, but this will change if the EPA designates fly ash as a hazardous waste.

Resolution: Stop the use of fly ash in LAUSD projects until the EPA confirms fly ash to be a non-hazardous, toxic waste.

Implementation Strategy: All projects

Cost Impact: Minimal to no cost impact

Cc: Lucy Padilla

Oscar Corcios OC 4/28/10

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1 ENR, January 5, 2009, P 12
2 Nadine N. Post, Fly Ash Looms as the "New Asbestos", ENR News, April 12, 2010, P 12

American Concrete Institute®
Advancing concrete knowledge

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Written Testimony

From: Richard D. Stehly, President, American Concrete Institute,
and Principal, American Engineering Testing, Inc.

Re: Coal Combustion Byproducts: Potential Impact of a Hazardous Waste Designation on Small Businesses in the Recycling Industry

Submitted to: U.S. House of Representatives, Committee on Small Business, Subcommittee on Rural Development, Entrepreneurship and Trade

July 22, 2010

Chairwoman Nydia M. Velazquez and members of the Subcommittee:

Thank you for the invitation to provide testimony during the hearing on "Coal Combustion Byproducts: Potential Impact of a Hazardous Waste Designation on Small Businesses in the Recycling Industry." The concrete industry comprises many small businesses, including contractors, design firms, and material suppliers. As the current President of the American Concrete Institute (ACI), I am pleased to represent ACI, one of the world's leading authorities on concrete technology. ACI is a 501(c)(3) non-profit technical and educational society organized in 1904. ACI is not a trade organization and has no commercial interest in concrete or concrete products. ACI members seek to advance concrete knowledge for the benefit of the general public.

ACI is an American National Standards Institute (ANSI) accredited Standards Developing Organization (SDO), and maintains national standards in the area of concrete technology and application. ACI currently supports more than 100 technical committees whose expert members develop these national standards using the consensus process. ACI maintains more than 400 technical documents, including codes, specifications, reports and guides, references, and the annual Manual of Concrete Practice.

As an ANSI-accredited SDO, two of ACI's major contributions to the construction industry are the "*ACI 318 Building Code Requirements for Structural Concrete and Commentary*" and "*ACI 530 Building Code Requirements for Masonry Structures and Commentary*", the latter produced jointly with the American Society of Civil Engineers and The Masonry Society. Both have been used by the major building codes in the past and are currently incorporated by reference in the 2009 International Building Code. ACI 318 contains references to the use of fly ash in concrete construction.

ACI 318 is used worldwide. An official ACI Spanish version is used throughout Central and South America. ACI has also authorized Arabic, Chinese, Korean, and Portuguese translations of ACI 318.

In regard to the beneficial use of fly ash in concrete, I offer the following:

Why is fly ash used in concrete?

Concrete is made by blending sand with crushed stone or gravel, and binding them together in a paste made with water and the powder known as portland cement. The manufacture of portland cement is not only an energy-intensive process, but the production of each ton of cement releases approximately 1 ton of CO_2 into the environment as a result of chemical conversions and the burning of fossil fuels. President Obama pledged at the UN Climate Summit in Denmark, Dec. 2009, to reduce CO_2 emissions 17% by 2020 over a 2005 baseline. Other industrialized nations are looking for U.S. leadership in this effort.

For over 50 years it has been shown that a reduction in the amount of cement required to produce concrete can be achieved by substituting coal fly ash for a significant portion of the portland cement. The resulting concrete not only has a lower embodied energy and CO_2 footprint, but also has improved properties leading to a more durable, longer lasting infrastructure. Fly ash is widely used in concrete produced in the U.S. today, and in this manner an industrial waste product is converted to a valuable resource. According to data from the American Coal Ash Association (ACAA), 15 million tons of fly ash otherwise destined for landfills were incorporated in concrete in 2006, preventing an approximately equivalent amount of CO_2 emissions.

Fly ash contributes to a more sustainable, environmentally responsible infrastructure because its use in concrete can:

- reduce concrete's embodied energy and CO_2 footprint;
- lower coal fly ash landfill volumes;
- increase the service life of concrete;
- tie-up trace metals in ash;
- enable the use of local marginal quality sand, crushed stone, and gravel and thus reduce the need to open new quarries and pits; and
- reduce the need and cost for repairs and maintenance.

Fly ash is vital to concrete performance because it can:

- be an effective ingredient in high-strength and high-performance concrete;
- reduce the porosity and penetrability of hardened concrete;
- be an effective ingredient in minimizing corrosion of reinforcing steel;
- be an effective ingredient in resisting severe environmental exposures;
- reduce the heat produced by chemical reaction of the cement (this is critical in dams, bridge piers, and large foundations);

- increase construction quality by making a more compactable concrete;
- lower concrete's initial and life-cycle cost; and
- reduce the need to import cement

There are no viable replacements for coal fly ash in concrete, in the short term, if its availability is reduced for any reason.

Fly ash used by the concrete industry is specified to meet the requirements of ASTM C618 and AASHTO M295, and as such is well understood. The use of coal fly ash is recognized for improving concrete durability in ACI's reference Code and Specification, and coal ash is discussed in over 100 of ACI's technical documents.

How does beneficial use impact CO_2 emissions for the concrete industry?

Life-cycle assessment research published by the Portland Cement Association (PCA) reported that 96% of the CO_2 embodied in concrete is derived from the manufacture of portland cement. Replacing a portion of the cement with an equivalent amount of fly ash can reduce the CO_2 footprint of concrete by up to 1 ton of CO_2 emissions for every 1 ton of cement replaced. Tracking cement use gives an indication of the concrete industry's CO_2 emissions. By using fly ash, the concrete industry could stay under the pledged target for CO_2 emissions reduction. This is true for every year including the target date of 2020.

How does beneficial use impact the need to import cement?

According to the statistics on cement use complied by the U.S. Geological Survey since 1900, cement use peaked at 128 million tons in 2005.

Based on industry trends and estimates from PCA, in 2009, approximately 75 million tons of cement was used, a 40% reduction from the 2005 level. ACAA's most recent data show that 15 million tons of fly ash was used in concrete construction in 2006. ACAA estimates that for 2008, 12 million tons of fly ash was used, with an additional 42 million tons available. When the economy recovers, fly ash could reduce the need to import cement and improve the balance of trade.

How might "stigma" impact beneficial use?

The title of the *Engineering-News Record* article "Fly Ash Looms as the 'New Asbestos'" (by Nadine Post, Apr. 7, 2010) points out the potentially harmful impact to the public perception toward the use of fly ash. But the EPA has had success in driving the use of materials labeled hazardous waste that have been reconditioned for reuse. Spent sulfuric acid is one example.

What is different about the concrete industry compared with other industries is the many different audiences it encompasses, and each has a stake in the use of fly ash. Fly ash generators have to assent to its use; otherwise, they can simply dispose of it. We Energies, a Wisconsin utility, has embraced the beneficial use of fly ash to the extent that in 2009 they recovered additional fly ash destined for disposal over what they produced that year. Ready mixed concrete suppliers have to be convinced that the improvements that might be needed at their facilities, such as additional silos for fly ash, will represent a return on the investment.

Concrete contractors also have to be in agreement. They are concerned with how fly ash impacts rate of strength gain and setting. The Engineer of Record has to approve the mixture design and must be convinced that fly ash will meet the requirements of the design. And the Owner of the project would question why fly ash is in the structure if it is hazardous. If EPA designates fly ash as special waste, but requires hazardous waste regulations, acceptance throughout the different audiences in the concrete industry will be difficult to maintain.

The American Concrete Institute is pleased to have worked with governmental agencies and industrial practitioners for over 100 years to develop building codes, specifications, standards, and guides that protect human safety and guide the design and construction of concrete infrastructure in the U.S. and around the world. As President of ACI, I am prepared to assist decision makers in selecting the best choices for the effective and responsible use of coal fly ash.

CEMENT STATISTICS[1]
U.S. GEOLOGICAL SURVEY
[All values in metric tons (t) cement unless otherwise noted]
Last modification: November 20, 2009

Year	Production	Imports	Exports	Stocks	Apparent consumption	Unit value ($/t)	Unit value (98$/t)	World production
1900	2,680,400	411,440	17,200		3,074,600	4.00	78.00	
1901	3,202,400	161,850	64,500		3,299,800	4.50	88.00	
1902	4,147,600	338,350	58,800		4,427,100	5.34	100	
1903	4,898,000	388,170	49,100		5,237,100	5.88	110	
1904	5,282,700	166,850	134,000		5,315,900	4.79	87.00	
1905	6,750,300	154,610	155,000		6,750,100	5.26	95.00	
1906	8,643,600	391,790	100,000		8,934,900	6.16	110	
1907	8,897,800	350,420	155,000		9,092,900	6.14	110	
1908	9,059,000	145,130	146,000		9,058,200	4.93	89.00	
1909	11,437,000	76,530	182,000		11,332,000	4.76	86.00	
1910	13,366,000	52,916	427,000		12,992,000	5.33	93.00	
1911	13,678,000	28,440	540,000	1,791,000	13,166,000	5.32	93.00	
1912	14,337,000	11,893	727,000	1,347,000	13,623,000	4.99	84.00	
1913	15,994,000	14,651	511,000	1,935,000	15,498,000	6.06	99.80	
1914	15,322,000	20,856	369,000	2,202,000	14,974,000	5.54	90.30	
1915	14,919,000	7,239	442,000	1,976,000	14,484,000	5.18	83.60	
1916	15,890,000	345	442,000	1,441,000	15,448,000	6.61	98.80	
1917	16,085,000	345	446,000	1,785,000	15,639,000	8.14	104	
1918	12,311,000	52	388,000	1,802,000	11,923,000	9.65	104	
1919	13,995,000	1,551	425,000	906,000	13,572,000	10.30	97.20	
1920	17,163,000	90,492	509,000	1,507,000	16,744,000	12.10	98.80	
1921	16,950,000	20,813	201,000	2,080,000	16,769,000	11.20	102	
1922	19,729,000	60,734	192,000	1,595,000	19,597,000	10.40	101	
1923	23,661,000	301,450	171,000	1,845,000	23,791,000	11.10	106	
1924	25,715,000	345,290	150,000	2,414,000	25,910,000	10.50	100	
1925	27,866,000	625,590	174,000	3,153,000	28,318,000	10.20	95.00	
1926	28,420,000	553,430	166,000	3,569,000	28,807,000	9.89	91.10	62,400,000
1927	29,903,000	349,730	139,000	3,856,000	29,540,000	9.43	88.30	67,800,000
1928	30,445,000	392,720	141,000	3,906,000	30,231,000	9.11	86.80	72,200,000
1929	29,481,000	297,700	151,000	4,076,000	29,202,000	8.66	82.50	74,900,000
1930	27,798,000	167,990	129,000	4,437,000	27,227,000	8.42	82.20	72,300,000
1931	21,604,000	80,159	73,300	4,191,000	21,745,000	6.51	69.80	62,100,000
1932	13,166,000	79,818	64,000	3,453,000	13,729,000	5.95	70.80	49,300,000
1933	10,913,000	81,353	116,000	3,334,000	10,860,000	7.83	98.20	48,200,000
1934	13,375,000	45,367	96,500	3,658,000	12,877,000	9.06	110	58,300,000
1935	13,260,000	105,570	70,900	3,935,000	12,745,000	8.81	105	65,400,000
1936	19,523,000	282,940	57,100	3,850,000	19,129,000	8.61	101	62,800,000
1937	20,138,000	323,020	64,600	4,250,000	19,469,000	8.45	95.60	82,700,000
1938	18,279,000	294,540	95,200	4,093,000	18,211,000	8.26	95.50	85,900,000
1939	21,212,000	326,430	195,000	4,034,000	21,046,000	8.43	98.90	93,000,000
1940	22,575,000	91,756	284,000	3,986,000	21,793,000	8.45	98.40	81,000,000
1941	28,387,000	7,334	436,000	3,406,000	28,378,000	8.61	95.50	88,000,000
1942	31,496,000	110	188,000	2,965,000	31,045,000	8.89	88.90	80,900,000
1943	22,901,000	2,388	295,000	3,956,000	21,226,000	9.16	86.30	71,200,000
1944	15,542,000	0	689,000	3,404,000	15,497,000	9.60	88.90	54,900,000
1945	17,537,000	55	1,100,000	2,836,000	17,378,000	9.56	86.50	49,500,000
1946	28,102,000	682	881,000	1,891,000	19,493,000	10.10	84.30	72,500,000
1947	31,995,000	853	1,150,000	1,733,000	32,634,000	11.10	81.40	85,800,000
1948	35,210,000	48,266	1,010,000	1,928,000	35,856,000	12.80	86.50	102,000,000
1949	35,939,000	18,761	778,000	2,545,000	36,265,000	13.50	92.40	115,000,000
1950	38,724,000	237,750	412,000	2,270,000	40,891,000	13.80	93.20	133,000,000
1951	41,825,000	151,960	500,000	3,109,000	42,695,000	14.90	93.40	149,000,000

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CEMENT STATISTICS[1]
U.S. GEOLOGICAL SURVEY
[All values in metric tons (t) cement unless otherwise noted]
Last modification: November 20, 2009

Year	Production	Imports	Exports	Stocks	Apparent consumption	Unit value ($/t)	Unit value (98$/t)	World production
1952	42,394,000	81,182	541,000	2,737,000	44,335,000	14.90	91.60	161,000,000
1953	45,021,000	65,321	435,000	3,312,000	46,047,000	15.70	95.90	178,000,000
1954	46,434,000	76,740	317,000	2,827,000	48,897,000	16.30	98.80	194,900,000
1955	52,994,000	810,630	306,000	2,982,000	53,589,000	17.00	103	217,300,000
1956	56,153,000	677,600	338,000	3,822,000	55,225,000	18.10	108	235,400,000
1957	52,574,000	734,220	227,000	4,903,000	51,638,000	18.80	109	246,900,000
1958	54,831,000	576,290	109,000	5,230,000	54,542,000	19.20	108	262,500,000
1959	59,764,000	896,930	47,200	5,362,000	59,899,000	19.40	108	294,300,000
1960	56,063,000	700,620	31,900	6,082,000	55,526,000	19.80	109	316,500,000
1961	56,718,000	617,560	48,800	6,211,000	56,826,000	19.60	107	333,200,000
1962	58,908,000	880,210	64,800	5,557,000	58,983,000	19.40	105	358,500,000
1963	61,733,000	678,450	78,600	6,736,000	63,648,000	18.90	101	378,000,000
1964	64,379,000	599,830	122,000	6,781,000	66,149,000	18.90	99.30	415,600,000
1965	65,078,000	874,410	128,000	5,618,000	67,589,000	18.70	96.50	433,400,000
1966	67,146,000	1,094,600	182,000	6,941,000	68,490,000	18.50	92.90	464,200,000
1967	64,449,000	985,440	167,000	7,083,000	67,459,000	18.60	90.70	479,800,000
1968	68,791,000	1,231,000	161,000	7,892,000	71,220,000	18.70	87.60	515,200,000
1969	71,086,000	1,548,400	100,000	7,129,000	71,101,000	18.90	84.11	543,100,000
1970	67,427,000	1,991,300	144,000	7,574,000	67,476,000	19.70	82.80	571,800,000
1971	71,054,000	2,141,000	99,800	6,425,000	72,842,000	21.00	84.34	590,000,000
1972	74,931,000	2,921,100	91,600	7,036,000	76,768,000	22.70	88.50	661,000,000
1973	77,576,000	3,577,000	295,000	5,512,000	81,941,000	24.50	89.96	702,000,000
1974	73,688,000	3,540,700	263,000	7,467,000	74,844,000	29.50	97.64	703,200,000
1975	61,815,000	2,263,400	448,000	6,930,000	63,608,000	34.60	105	702,200,000
1976	66,179,000	1,945,900	423,000	7,154,000	67,509,000	37.80	108	735,400,000
1977	70,939,000	2,180,000	217,000	6,041,000	73,427,000	40.50	109	797,100,000
1978	76,190,000	3,292,200	52,600	5,320,000	79,288,000	45.40	114	853,000,000
1979	76,649,000	4,304,600	137,000	6,600,000	78,964,000	51.40	115	872,400,000
1980	68,242,000	3,035,400	169,000	6,825,000	70,173,000	56.60	112	883,100,000
1981	65,054,000	2,513,800	275,000	6,688,000	66,092,000	57.80	104	886,700,000
1982	57,475,000	2,230,800	184,000	6,753,000	59,572,000	56.70	95.80	887,400,000
1983	63,884,000	2,960,100	107,000	6,711,000	65,838,000	55.60	91.00	916,600,000
1984	70,488,000	6,015,500	72,600	6,866,000	76,186,000	57.20	89.70	941,100,000
1985	70,665,000	8,939,400	88,900	7,232,000	78,836,000	55.90	84.70	959,400,000
1986	71,473,000	11,201,000	53,500	6,725,000	82,837,000	54.80	81.50	1,008,000,000
1987	70,940,000	12,753,000	47,200	6,159,000	84,204,000	54.40	78.10	1,053,000,000
1988	69,733,000	14,124,000	91,600	5,997,000	83,851,000	54.80	75.50	1,118,000,000
1989	70,025,000	12,697,000	464,000	5,715,000	82,414,000	54.80	72.00	1,042,000,000
1990	69,954,000	10,344,000	503,000	5,637,000	80,964,000	55.30	69.00	1,043,000,000
1991	66,755,000	6,548,000	633,000	6,009,000	71,800,000	55.50	66.40	1,185,000,000
1992	69,585,000	4,582,000	746,000	5,272,000	76,169,000	55.30	64.30	1,123,000,000
1993	73,807,000	5,532,000	625,000	4,788,000	79,701,000	56.40	63.60	1,291,000,000
1994	77,948,000	9,074,000	633,000	4,701,000	86,476,000	61.90	68.10	1,370,000,000
1995	76,906,000	10,969,000	759,000	5,814,000	86,003,000	67.80	72.60	1,445,000,000
1996	79,266,000	11,565,000	803,000	5,488,000	90,355,000	70.90	73.60	1,493,000,000
1997	82,582,000	14,523,000	791,000	5,784,000	96,018,000	73.50	74.60	1,547,000,000
1998	83,931,000	19,878,000	743,000	5,393,000	103,457,000	76.50	76.50	1,540,000,000
1999	85,952,000	24,578,000	694,000	6,367,000	108,862,000	78.30	76.60	1,600,000,000
2000	87,846,000	24,561,000	738,000	7,566,000	110,470,000	78.60	74.40	1,660,000,000
2001	88,900,000	23,694,000	746,000	6,600,000	112,800,000	76.50	70.40	1,750,000,000
2002	89,732,000	22,198,000	834,000	7,680,000	110,020,000	76.00	68.80	1,850,000,000
2003	92,843,000	21,015,000	837,000	6,610,000	114,090,000	75.00	66.40	2,020,000,000

CEMENT STATISTICS[1]
U.S. GEOLOGICAL SURVEY
[All values in metric tons (t) cement unless otherwise noted]
Last modification: November 20, 2009

Year	Production	Imports	Exports	Stocks	Apparent consumption	Unit value ($/t)	Unit value (98$/t)	World production
2004	97,434,000	25,396,000	749,000	6,710,000	121,980,000	79.50	68.60	2,190,000,000
2005	99,319,000	30,403,000	766,000	7,450,000	128,280,000	91.00	75.90	2,350,000,000
2006	98,167,000	32,141,000	723,000	9,380,000	127,700,000	101.50	82.10	2,610,000,000
2007	95,464,000	21,496,000	886,000	8,890,000	116,564,000	104.00	81.80	2,810,000,000
2008	86,381,000	10,744,000	858,000	8,360,000	96,797,000	103.00	78.00	2,840,000,000

[1]Compiled by T.D. Kelly (retired) and H.G. van Oss.
Data are calculated, estimated, or reported. See notes for more information.

Cement Worksheet Notes

Data Sources
The sources of data for the cement worksheet are the mineral statistics publications of the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey—Minerals Yearbook (MYB) and its predecessor, Mineral Resources of the United States (MR). The years of publication and corresponding years of data coverage are listed in the References section below. Blank cells in the worksheet indicate that data were not available.

Production
Production data report the sum of portland, natural, masonry, and slag or pozzolanic cement (all hydraulic cement) as published in the MYB and the MR. Beginning in 1922, the term masonry cement was introduced as a category of hydraulic cement consisting of natural and pozzolanic cements as well as masonry cement to prevent the reporting of proprietary data.

Imports
Import data prior to 1950 are assumed to include clinker. Original footnotes indicate a change in USBM reporting methods for imports, beginning in 1954. Data do not allow calculation of clinker imports prior to 1950. Import data for hydraulic cement were recorded from the published values in the MYB and the MR.

Exports
Export data include hydraulic cement and clinker. Data were recorded from the MYB and the MR.

Stocks
Yearend stocks of cement at mills and terminals were recorded from the MYB and the MR. Stocks data were not available from 1900–10.

Apparent Consumption
Apparent consumption of hydraulic cement was recorded from the MYB and the MR.

Unit Value ($/t)
Unit value is defined as the value of 1 metric ton (t) of cement apparent consumption in current dollars. For the years 1900–44, unit value is estimated from the weighted-average production values of pozzolanic cement, natural cement, and portland cement. From 1945 to the most recent year, the reported bulk value at the mill is used to estimate unit value. The reported bulk value at the mill is a weighted-average value of all forms of portland cement and masonry cement. All values and prices were recorded from the MYB and the MR.

Unit Value (98$/t)
The Consumer Price Index conversion factor, with 1998 as the base year, is used to adjust unit value in current U.S. dollars to the unit value in constant 1998 U.S. dollars.

World Production
World production of hydraulic cement was recorded from the MYB and the MR. World production statistics were not available from 1900–25.

References
U.S. Bureau of Mines, 1927–34, Mineral Resources of the United States, 1924–31.
U.S. Bureau of Mines, 1933–96, Minerals Yearbook, 1932–94.
U.S. Geological Survey, 1901–27, Mineral Resources of the United States, 1900–23.
U.S. Geological Survey, 1997–2009, Minerals Yearbook, v. I, 1995–2008.

Recommended Citation Format:
U.S. Geological Survey, [year of last update, e.g., 2005], [Mineral commodity, e.g., Gold] statistics, in Kelly, T.D., and Matos, G.R., comps., Historical statistics for mineral and material commodities in the United States: U.S. Geological Survey Data Series 140, available online at http://pubs.usgs.gov/ds/2005/140/. (Accessed [date].)

For more information, please contact:

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McGraw Hill CONSTRUCTION ENR

Fly Ash Looms As The 'New Asbestos'

Groups fear negative impact on concrete use if proposed federal rule becomes reality

04/07/2010

By Nadine M. Post

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Concrete groups are on tenterhooks, waiting for the U.S. Environmental Protection Agency to publish a proposed rule that aims to designate fly ash and other coal-combustion by-products as hazardous waste. The concrete sector is concerned even about the ramifications of a "hybrid" rule that would allow beneficial uses of CCBs to continue.

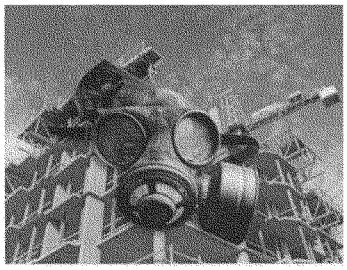

Photo: Sue Pearsall/ENR

Proposed federal rule would complicate production and disposal of concrete structures.

Major among these beneficial uses is fly ash in concrete. The ingredient, a partial replacement for portland cement, is known to increase concrete's constructibility, durability and sustainability.

Concrete stakeholders say a hazardous-waste designation for fly ash would make it the "new asbestos" or "new lead paint," dragging concrete into the fray. Questions would arise over the handling practices of both materials during production and casting as well as during the demolition and disposal of concrete structures.

A hazardous-waste designation for fly ash would "stigmatize its use as an ingredient in concrete, even if EPA were to focus a designation only on fly ash that is disposed rather than beneficially reused," says Andrew T. O'Hare, vice president of regulatory affairs in Portland Cement Association's Washington, D.C., office.

EPA's possible action has pitted environmentalists against industry groups and threatened future building plans, including a $50-million fly-ash recycling facility.

The issue has raised many questions. Is it dangerous if someone drills a hole in concrete with sequestered fly ash? Should workers wear respirators? Are existing structures that contain sequestered fly ash a health hazard if they are demolished? Would contractors have to follow containment practices as they do for lead paint and asbestos? Would the material have to go to hazardous-waste landfills?

"It's very complicated," says Scot Horst, senior vice president in charge of the green-building rating system Leadership in Energy and Environmental Design (LEED), published by the U.S. Green Building Council, Washington, D.C. "If fly ash is a hazardous waste and it becomes part of a concrete wall, is the wall a hazardous material?"

Legal issues would also come into play. "In these risk-averse times, many end users of fly ash," including concrete producers and construction companies, "would be discouraged by counsel to use

fly ash, noting that it is not absolutely necessary," says Thomas Adams, executive director of the American Coal Ash Association, Aurora, Colo.

In discussions, structural engineers, consultants, concrete producers, contractors and owners have indicated they would reject use of fly ash in concrete if there were potential exposure to creative tort activity, says Adams. "Attorneys have demonstrated that litigation can be initiated even without demonstrated damage," he adds.

Contractors also are concerned about the impact of an EPA ruling on insurance. It's likely that fly ash would not be covered in new policies, says Adams.

EPA is considering reclassifying fly ash as a hazardous waste under Subtitle C of the Resource Conservation and Recovery Act. The action is a response to the Dec. 22, 2008, collapse of an earthen retaining wall of a containment structure at the Tennessee Valley Authority's Kingston, Tenn., coal plant. The failure sent 5.4 million cu yd of toxic sludge, containing fly ash and water, flowing over 300 acres. The spill is considered the worst breech of its kind in the U.S.

Cement and concrete groups are calling for measures to ensure proper CCB containment, not overreaction. "The...

[Page 2 of 2] PREVIOUS

Fly Ash Looms As The 'New Asbestos'

Groups fear negative impact on concrete use if proposed federal rule becomes reality
04/07/2010

By Nadine M. Post

...spill was obviously an environmental catastrophe, but it appears some officials are casting too wide a net to address this incident," says Claude Goguen, director of technical services at the National Precast Concrete Association, Carmel, Ind.

In 1993 and 2000, EPA determined CCBs did not warrant management as hazardous waste. Last October, EPA delivered its proposed rule to the Office of Management and Budget for interagency review and comment. The proposal is still in the hands of OMB, with no indication of when its review will be completed. EPA said in a statement, "This rule continues to be under review, and we expect to issue a proposed rule in the near future."

The nonprofit American Concrete Institute (ACI), which publishes technical standards, has concerns about EPA's proposed rule. Of some 400 standards and technical documents, 106 would have to be revisited were fly ash ruled to be a hazardous waste. These standards include ACI 232, which outlines the use and application of fly ash, and ACI 318, the model concrete code.

"Even if it is a hybrid ruling, we would need to evaluate the impact on applications and our documents," says Florian Barth, ACI's 2009-10 president and a consultant based in Los Gatos, Calif. Document review could take several years, he says, because ACI relies on its member volunteers to develop its standards.

In 2008 in the U.S., 136 million tons of CCBs were produced, according to a survey by the American Coal Ash Association (ACAA). Almost 16 million tons were used in cement and concrete production. Another 8.5 million tons went into the production of wallboard products. The use of fly ash instead of portland cement, which is an energy-intensive product, avoided 12 million tons of carbon dioxide

emissions, says ACAA.

In the U.S., fly ash use in concrete ramped up beginning in the 1980s. Since 2000, the recycling rate for CCBs has increased to 44% from 30%, says ACAA. During that time, more than 1.1 billion tons of CCBs were produced, with 430 million tons recycled. In the U.S., CCBs are the second-largest waste stream after municipal solid waste, says ACAA.

A hazardous waste designation for fly ash would "stigmatize its use as an ingredient in concrete."

— ANDREW T. O'HARE, VICE PRESIDENT OF REGULATORY AFFAIRS,PORTLAND CEMENT ASSOCIATION

Use of fly ash in concrete is considered environmentally responsible because it reduces cement content, from 15% to 25%. That, in turn, reduces the carbon dioxide generated in cement production. In 2007, there was a 15-million-ton reduction of CO_2 production, says ACI.

Fly ash makes concrete less permeable, which reduces infiltration of water and aggressive chemicals. The material resists unwanted alkali-aggregate and sulfate reactions, says ACI. It also increases concrete's compressive strength, improves the workability of fresh concrete and reduces heat of hydration in mass concrete.

Fly ash is recognized by the LEED rating system as a postindustrial recycled material. "We respect EPA's ability and role as a regulator ... and are quite sure there is alignment around the beneficial use of fly ash," says Horst. However, "if EPA designates fly ash as a hazardous waste, LEED committees will take a look at the rating system."

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ACI 229R-99
(Reapproved 2005)

Controlled Low-Strength Materials

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Controlled low-strength material (CLSM) is a self-compacted, cementitious material used primarily as a backfill in place of compacted fill. Many terms are currently used to describe this material, including flowable fill, unshrinkable fill, controlled density fill, flowable mortar, flowable fly ash, fly ash slurry, plastic soil-cement, soil-cement slurry and other various names. This report contains information on applications, material properties, mix proportioning, construction, and quality-control procedures. The intent of this report is to provide basic information on CLSM technology, with emphasis on CLSM material characteristics and advantages over conventional compacted fill.

Keywords: aggregates; backfill; compacted fill; controlled density fill; controlled low-strength material; flowable fill; flowable mortar; fly ash; foundation stabilization; low-density material; pipe bedding; plastic soil-cement; preformed foam; soil-cement slurry; trench backfill; unshrinkable fill; void filling.

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CHAPTER 1—INTRODUCTION

Controlled low-strength material (CLSM) is a self-compacted, cementitious material used primarily as a backfill as an alternative to compacted fill. Several terms are currently used to describe this material, including flowable fill, unshrinkable fill, controlled density fill, flowable mortar, plastic soil-cement, soil-cement slurry, and other various names.

Controlled low-strength materials are defined by ACI 116R as materials that result in a compressive strength of 8.3 MPa (1200 psi) or less. Most current CLSM applications require unconfined compressive strengths of 2.1 MPa (300 psi) or less. This lower-strength requirement is necessary to allow for future excavation of CLSM.

The term CLSM can be used to describe a family of mixtures for a variety of applications. For example, the upper limit of 8.3 MPa (1200 psi) allows use of this material for applications where future excavation is unlikely, such as structural fill under buildings. Chapter 8 of this report describes low-density (LD) CLSM produced using preformed foam as part of the mixture proportioning. The use of preformed foam in LD-CLSM mixtures allow these materials to be produced having unit weights lower than those of typical CLSM. The distinctive properties and mixing procedures for LD-CLSM are discussed in the chapter. Future CLSM mixtures can be developed as anticorrosion fills, thermal fills, and durable pavement bases.

CLSM should not be considered as a type of low-strength concrete, but rather a self-compacted backfill material that is used in place of compacted fill. Generally, CLSM mixtures are not designed to resist freezing and thawing, abrasive or erosive forces, or aggressive chemicals. Nonstandard materials can be used to produce CLSM as long as the materials have been tested and found to satisfy the intended application.

Also, CLSM should not be confused with compacted soil-cement, as reported in ACI 230.1R. CLSM typically requires no compaction (consolidation) or curing to achieve the desired strength. Long-term compressive strengths for compacted soil-cement often exceed the 8.3 MPa (1200 psi) maximum limit established for CLSM.

Long-term compressive strengths of 0.3 to 2.1 MPa (50 to 300 psi) are low when compared with concrete. In terms of allowable bearing pressure, however, which is a common criterion for measuring the capacity of a soil to support a load, 0.3 to 0.7 MPa (50 to 100 psi) strength is equivalent to a well-compacted fill.

Although CLSM generally costs more per yd^3 than most soil or granular backfill materials, its many advantages often result in lower in-place costs. In fact, for some applications, CLSM is the only reasonable backfill method available.[1-3] Table 1 lists a number of advantages to using CLSM.[4]

CHAPTER 2—APPLICATIONS

2.1—General

As stated earlier, the primary application of CLSM is as a structural fill or backfill in lieu of compacted soil. Because CLSM needs no compaction and can be designed to be fluid, it is ideal for use in tight or restricted-access areas where placing and compacting fill is difficult. If future excavation is anticipated, the maximum long-term compressive strength should generally not exceed 2.1 MPa (300 psi). The following applications are intended to present a range of uses for CLSM.[5]

2.2—Backfills

CLSM can be readily placed into a trench, hole or other cavity (Fig. 2.1 and 2.2). Compaction is not required; hence, the trench width or size of excavation can be reduced. Granular or site-excavated backfill, even if compacted properly in the required layer thickness, can not achieve the uniformity and density of CLSM.[5]

When backfilling against retaining walls, consideration should be given to the lateral pressures exerted on the wall by flowable CLSM. Where the lateral fluid pressure is a concern, CLSM can be placed in layers, allowing each layer to harden prior to placing the next layer.

Following severe settlement problems of soil backfill in utility trenches, the city of Peoria, Ill., in 1988, tried CLSM as an alternative backfill material. The CLSM was placed in trenches up to 2.7 m (9 ft) deep. Although fluid at time of placement, the CLSM hardened to the extent that a person's weight could be supported within 2 to 3 hr. Very few shrinkage cracks were observed. Further tests were conducted on patching the overlying pavement within 3 to 4 hr. In one test, a pavement patch was successfully placed over a sewer trench

Table 1—Cited advantages of controlled low-strength materials[4]

Readily available	Using locally available materials, ready-mixed concrete suppliers can produce CLSM to meet most project specifications.
Easy to deliver	Truck mixers can deliver specified quantities of CLSM to job site whenever material is needed.
Easy to place	Depending on type and location of void to be filled, CLSM can be placed by chute, conveyor, pump, or bucket. Because CLSM is self-leveling, it needs little or no spreading or compacting. This speeds construction and reduces labor requirements.
Versatile	CLSM mixtures can be adjusted to meet specific fill requirements. Mixes can be adjusted to improve flowability. More cement or fly ash can be added to increase strength. Admixtures can be added to adjust setting times and other performance characteristics. Adding foaming agents to CLSM produces lightweight, insulating fill.
Strong and durable	Load-carrying capacities of CLSM are typically higher than those of compacted soil or granular fill. CLSM is also less permeable, thus more resistant to erosion. For use as permanent structural fill, CLSM can be designed to achieve 28-day compressive strength as high as 8.3 MPa (1200 psi).
Allows fast return to traffic	Because many CLSMs can be placed quickly and support traffic loads within several hours, downtime for pavement repairs is minimal.
Will not settle	CLSM does not form voids during placement and will not settle or rut under loading. This advantage is especially significant if backfill is to be covered by pavement patch. Soil or granular fill, if not consolidated properly, may settle after a pavement patch is placed and forms cracks or dips in the road.
Reduces excavation costs	CLSM allows narrower trenches because it eliminates having to widen trenches to accommodate compaction equipment.
Improves worker safety	Workers can place CLSM in a trench without entering the trench, reducing their exposure to possible cave-ins.
Allows all-weather construction	CLSM will typically displace any standing water left in a trench from rain or melting snow, reducing need for dewatering pumps. To place CLSM in cold weather, materials can be heated using same methods for heating ready-mixed concrete.
Can be excavated	CLSM having compressive strengths of 0.3 to 0.7 MPa (50 to 100 psi) is easily excavated with conventional digging equipment, yet is strong enough for most backfilling needs.
Requires less inspection	During placement, soil backfill must be tested after each lift for sufficient compaction. CLSM self-compacts consistently and does not need this extensive field testing.
Reduces equipment needs	Unlike soil or granular backfill, CLSM can be placed without loaders, rollers, or tampers.
Requires no storage	Because ready-mixed concrete trucks deliver CLSM to job site in quantities needed, storing fill materials on site is unnecessary. Also, there is no leftover fill to haul away.
Makes use of coal combustion product	Fly ash is by-product produced by power plants that burn coal to generate electricity. CLSM containing fly ash benefits environment by making use of this industrial product material.

immediately after backfilling with CLSM. As a result of these initial tests, the city of Peoria has changed its backfilling procedure to require the use of CLSM on all street openings.[4]

Some agencies backfill with a CLSM that has a setting time of 20 to 35 min. (after which time a person can walk on it). After approximately 1 hr, the wearing surface consisting of either a rapid-setting concrete or asphalt pavement is placed, resulting in a total traffic-bearing repair in about 4 hr.[6]

2.3—Structural fills

Depending upon the strength requirements, CLSM can be used for foundation support. Compressive strengths can vary from 0.7 to 8.3 MPa (100 to 1200 psi) depending upon application. In the case of weak soils, it can distribute the structure's load over a greater area. For uneven or nonuniform subgrades under foundation footings and slabs, CLSM can provide a uniform and level surface. Compressive strengths will vary depending upon project requirements. Because of its strength, CLSM may reduce the required thickness or strength requirements of the slab. Near Boone, Iowa, 2141 m^3 (2800 yd^3) of CLSM was used to provide proper bearing capacity for the footing of a grain elevator.[7]

2.4—Insulating and isolation fills

LD-CLSM material is generally used for these applications. Chapter 8 addresses LD-CLSM material using preformed foam.

2.5—Pavement bases

CLSM mixtures can be used for pavement bases, subbases, and subgrades. The mixture would be placed directly from the mixer onto the subgrade between existing curbs. For base course design under flexible pavements, structural coefficients differ depending upon the strength of the CLSM. Based on structural coefficient values for cement-treated bases derived from data obtained in several states, the structural coefficient of a CLSM layer can be estimated to range from 0.16 to 0.28 for compressive strengths from 2.8 to 8.3 MPa (400 to 1200 psi).[8]

Good drainage, including curb and gutter, storm sewers, and proper pavement grades, is required when using CLSM mixtures in pavement construction. Freezing and thawing damage could result in poor durability if the base material is frozen when saturated with water.

A wearing surface is required over CLSM because it has relatively poor wear-resistance properties. Further information regarding pavement base materials is found in ACI 325.3R.

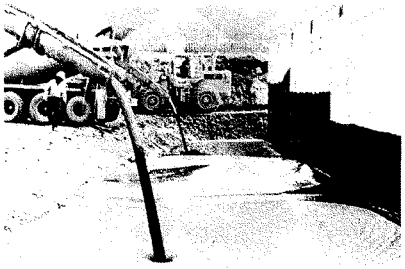

Fig. 2.1—Using CLSM to backfill adjacent to building foundation wall.

2.6—Conduit bedding

CLSM provides an excellent bedding material for pipe, electrical, telephone, and other types of conduits. The flowable characteristic of the material allows the CLSM to fill voids beneath the conduit and provide a uniform support.

The U.S. Bureau of Reclamation (USBR) began using CLSM in 1964 as a bedding material for 380 to 2400 mm (15 to 96 in.) diameter concrete pipe along the entire Canadian River Aqueduct Project, which stretches 518 km (322 miles) from Amarillo to Lubbock, Tex. Soil-cement slurry pipe bedding, as referred to by the USBR, was produced in central portable batching plants that were moved every 16 km (10 miles) along the route. Ready-mixed concrete trucks then delivered the soil-cement slurry to the placement site. The soil was obtained from local blow sand deposits. It was estimated that the soil-cement slurry reduced bedding costs 40%. Production increased from 120 to 300 m (400 to 1000 linear ft) of pipe placed per shift.[9]

CLSM can be designed to provide erosion resistance beneath the conduit. Since the mid-1970s, some county agencies in Iowa have been placing culverts on a CLSM bedding. This not only provides a solid, uniform pipe bedding, but prevents water from getting between the pipe and bedding, eroding the support.[10]

Encasing the entire conduit in CLSM also serves to protect the conduit from future damage. If the area around the conduit is being excavated at a later date, the obvious material change in CLSM versus the surrounding soil or conventional granular backfill would be recognized by the excavating crew, alerting them to the existence of the conduit. Coloring agents have also been used in mixtures to help identify the presence of CLSM.

2.7—Erosion control

Laboratory studies, as well as field performance, have shown that CLSM resists erosion better than many other fill materials. Tests comparing CLSM with various sand and clay fill materials showed that CLSM, when exposed to a water velocity of 0.52 m/sec (1.7 ft/sec), was superior to the other materials, both in the amount of material loss and suspended solids from the material.[11]

Fig. 2.2—Backfilling utility cut with CLSM.

CLSM is often used in riprap for embankment protection and in spilling basins below dam spillways, to hold rock pieces in place and resist erosion. CLSM is used to fill flexible fabric mattresses placed along embankments for erosion protection, thereby increasing their strength and weight. In addition to providing an erosion resistance under culverts, CLSM is used to fill voids under pavements, sidewalks, bridges and other structures where natural soil or noncohesive granular fill has eroded away.

2.8—Void filling

2.8.1 *Tunnel shafts and sewers*—When filling abandoned tunnels and sewers, it is important to use a flowable mixture. A constant supply of CLSM will help keep the material flowing and make it flow greater distances. CLSM was used to fill an abandoned tunnel that passed under the Menomonee River in downtown Milwaukee, Wis. The self-leveling material flowed over 71.6 m (235 ft). On another Milwaukee project, 635 m^3 (831 yd^3) were used to fill an abandoned sewer. The CLSM reportedly flowed up to 90 m (300 linear ft).[12]

Before constructing the Mount Baker Ridge Tunnel in Seattle, Wash., an exploratory shaft 37 m (120 ft) deep, 3.7 m (12 ft) in diameter with 9.1 m (30 ft) long branch tunnels was excavated. After exploration, the shaft had to be filled before

construction of the tunnel. Only 4 hr were needed to fill the shaft with 601 m^3 (786 yd^3) of CLSM.[13]

2.8.2 *Basements and underground structures*—Abandoned basements are often filled in with CLSM by pumping or conveying the mixture through an open window or doorway. An industrial renovation project in LaSalle, Ill., required the filling of an existing basement to accommodate expansion plans. Granular fill was considered, but access problems made CLSM a more attractive alternative. About 300 m^3 (400 yd^3) of material were poured in one day. A 200 mm (8 in.) concrete floor was then placed directly on top of the CLSM mixture.[14]

In Seattle, buses were to be routed off busy streets into a tunnel with pedestrian stations.[13] The tunnel was built by a conventional method, but the stations had to be excavated from the surface to the station floor. After the station was built, there was a 19,000 m^3 (25,000 yd^3) void over each station to the street. So as not to disrupt traffic with construction equipment and materials, the voids were filled with CLSM, which required no layered placement or compaction.

CLSM has been used to fill abandoned underground storage tanks (USTs). Federal and State regulations have been developed that address closure requirements for underground fuel and chemical tanks. USTs taken out of service permanently must either be removed from the ground or filled with an inert solid material. The Iowa Department of Natural Resources has developed a guidance document for storage tank closures, which specifically mentions flowable fill.

2.8.3 *Mines*—Abandoned mines have been filled with CLSM to eliminate access, prevent subsidence, bottle up hazardous gases, cut off the oxygen supply for fires, and reduce or eliminate acid drainage. It is important that a flowable mixture be placed with a constant supply to facilitate the spread and minimize the quantity of injection/placement points. The western U.S. alone contains approximately 250,000 abandoned mines with various hazards.[15] CLSM can be used to fill mine voids completely, or in areas of particular concern, to prevent subsidence, block trespasser entry, and eliminate or reduce acid or other harmful drainage. Abandoned underground coal mines in the eastern U.S. have been filled using CLSM that was manufactured from various coal combustion products for this purpose.[6,15-17]

2.9—Nuclear facilities

CLSM is used in nuclear facilities for conventional applications such as those described previously. It provides a significant advantage over conventional granular backfill in that remote placement decreases personnel exposure to radiation. CLSM can also be used in unique applications at nuclear facilities, such as waste stabilization, encapsulation of decommissioned pipelines and tanks, encapsulation of waste-disposal sites, and new landfill construction. CLSM can be used to address a wide range of chemical and radionuclide-stabilization requirements.[18-20]

2.10—Bridge reclamation

CLSM has been used in several states as part of a cost-effective process for bridge rehabilitation. The process requires putting enough culverts under the bridge to handle the hydrology requirements. A dam is placed over both ends of the culvert(s) and the culvert(s) are covered with fabric to keep the CLSM from flowing into the joints. These culvert(s) are set on granular backfill. The CLSM is then placed until it is 150 mm (6 in.) from the lower surface of the deck. A period of at least 72 hr is required before the CLSM is brought up to the bottom of the deck through holes cored in the deck. Later, the railing is removed and the deck is widened. The same procedure is then completed on the opposite side of the bridge. The work is done under traffic conditions. The camber of the roadway over the culvert(s) is the only clue that a bridge had ever been present. Iowa DOT officials estimate that the cost of four reclamations is equivalent to one replacement when this technology can be employed.[10,21,22]

CHAPTER 3—MATERIALS

3.1—General

Conventional CLSM mixtures usually consist of water, portland cement, fly ash or other similar products, and fine or coarse aggregates or both. Some mixtures consist of water, portland cement, and fly ash only. Special low-density CLSM (LD-CLSM) mixtures, as described in Chapter 8 of this report, consist of portland cement, water, and preformed foam.

Although materials used in CLSM mixtures meet ASTM or other standard requirements, the use of standardized materials is not always necessary. Selection of materials should be based on availability, cost, specific application, and the necessary characteristics of the mixture, including flowability, strength, excavatability, and density.

3.2—Cement

Cement provides the cohesion and strength for CLSM mixtures. For most applications, Type I or Type II portland cement conforming to ASTM C 150 is normally used. Other types of cement, including blended cements conforming to ASTM C 595, can be used if prior testing indicates acceptable results.

3.3—Fly ash

Coal-combustion fly ash is sometimes used to improve flowability. Its use can also increase strength and reduce bleeding, shrinkage, and permeability. High fly ash-content mixtures result in lower-density CLSM when compared with mixtures with high aggregate contents. Fly ashes used in CLSM mixtures do not need to conform to either Class F or C as described in ASTM C 618. Trial mixtures should be prepared to determine whether the mixture will meet the specified requirements. Refer to ACI 232.2R for further information.[23,24]

3.4—Admixtures

Air-entraining admixtures and foaming agents can be valuable constituents for the manufacture of CLSM. The inclusion of air in CLSM can help provide improved workability, reduced shrinkage, little or no bleeding, minimal segregation, lower unit weights, and control of ultimate strength development. Higher air contents can also help enhance CLSM's thermal insulation and freeze-thaw properties. Water content can be

reduced as much as 50% when using air-entraining admixtures. The use of these materials may require modifications to typical CLSM mixtures. To prevent segregation when utilizing high air contents, the mixtures need to be proportioned with sufficient fines to promote cohesion. Most air-entrained CLSM mixtures are pumpable but can require higher pump pressures when piston pumps are used. To prevent extended setting times, extra cement or the use of an accelerating admixture may be required. In all cases, pretesting should be performed to determine acceptability.[6,25,26]

3.5—Other additives

In specialized applications such as waste stabilization, CLSM mixtures can be formulated to include chemical and/or mineral additives that serve purposes beyond that of simple backfilling. Some examples include the use of swelling clays such as bentonite to achieve CLSM with low permeability. The inclusion of zeolites, such as analcime or chabazite, can be used to absorb selected ions where water or sludge treatment is required. Magnetite or hematite fines can be added to CLSM to provide radiation shielding in applications at nuclear facilities.[18-20]

3.6—Water

Water that is acceptable for concrete mixtures is acceptable for CLSM mixtures. ASTM C 94 provides additional information on water-quality requirements.

3.7—Aggregates

Aggregates are often the major constituent of a CLSM mixture. The type, grading, and shape of aggregates can affect the physical properties, such as flowability and compressive strength. Aggregates complying with ASTM C 33 are generally used because concrete producers have these materials in stock.

Granular excavation materials with somewhat lower-quality properties than concrete aggregate are a potential source of CLSM materials, and should be considered. Variations of the physical properties of the mixture components, however, will have a significant effect on the mixture's performance. Silty sands with up to 20% fines passing through a 75 µm (No. 200) sieve have proven satisfactory. Also, soils with wide variations in grading have shown to be effective. Soils with clay fines, however, have exhibited problems with incomplete mixing, stickiness of the mixtures, excess water demand, shrinkage, and variable strength. These types of soils are not usually considered for CLSM applications. Aggregates that have been used successfully include:[27]

- ASTM C 33 specification aggregates within specified gradations;
- Pea gravel with sand;
- 19 mm (3/4 in.) minus aggregate with sand;
- Native sandy soils, with more than 10% passing a 75 µm (No. 200) sieve;
- Quarry waste products, generally 10 mm (3/8 in.) minus aggregates.

3.8—Nonstandard materials

Nonstandard materials, which can be available and more economical, can also be used in CLSM mixtures, depending upon project requirements. These materials, however, should be tested prior to use to determine their acceptability in CLSM mixtures.

Examples of nonstandard materials that can be substituted as aggregates for CLSM include various coal combustion products, discarded foundry sand, glass cullet, and reclaimed crushed concrete.[28-30]

Aggregates or mixtures that might swell in service due to expansive reactions or other mechanisms should be avoided. Also, wood chips, wood ash, or other organic materials may not be suitable for CLSM. Fly ashes with carbon contents up to 22% have been successfully used for CLSM.[31]

In all cases, the characteristics of the nonstandard material should be determined, and the suitability of the material should be tested in a CLSM mixture to determine whether it meets specified requirements. In certain cases, environmental regulations could require prequalification of the raw material or CLSM mixture, or both, prior to use.

3.9—Ponded ash or basin ash

Ponded ash, typically a mixture of fly ash and bottom ash slurried into a storage/disposal basin, can also be used in CLSM. The proportioning of the ponded ash in the resulting mixtures depends on its particle size distribution. Typically, it can be substituted for all of the fly ash and a portion of the fine aggregate and water. Unless dried prior to mixing, ponded ash requires special mixing because it is usually wet. Basin ash is similar to ponded ash except it is not slurried and can be disposed of in dry basins or stockpiles.[18-20]

CHAPTER 4—PROPERTIES

4.1—Introduction

The properties of CLSM cross the boundaries between soils and concrete. CLSM is manufactured from materials similar to those used to produce concrete, and is placed from equipment in a fashion similar to that of concrete. In-service CLSM, however, exhibits characteristic properties of soils. The properties of CLSM are affected by the constituents of the mixture and the proportions of the ingredients in the mixture. Because of the many factors that can affect CLSM, a wide range of values may exist for the various properties discussed in following sections.[32]

4.2—Plastic properties

4.2.1 *Flowability*—Flowability is the property that distinguishes CLSM from other fill materials. It enables the materials to be self-leveling; to flow into and readily fill a void; and be self-compacting without the need for conventional placing and compacting equipment. This property represents a major advantage of CLSM compared with conventional fill materials that must be mechanically placed and compacted. Because plastic CLSM is similar to plastic concrete and grout, its flowability is best viewed in terms of concrete and grout technology.

A major consideration in using highly flowable CLSM is the hydrostatic pressure it exerts. Where fluid pressure is a

concern, CLSM can be placed in lifts, with each lift being allowed to harden before placement of the next lift. Examples where multiple lifts can be used are in the case of limited-strength forms that are used to contain the material, or where buoyant items, such as pipes, are encapsulated in the CLSM.

Flowability can be varied from stiff to fluid, depending upon requirements. Methods of expressing flowability include the use of a 75 x 150 mm (3 x 6 in.) open-ended cylinder modified flow test (ASTM D 6103), the standard concrete slump cone (ASTM C 143), and flow cone (ASTM C 939).

Good flowability, using the ASTM D 6103 method, is achieved where there is no noticeable segregation and the CLSM material spread is at least 200 mm (8 in.) in diameter. Flowability ranges associated with the slump cone can be expressed as follows:[33]

- Low flowability: less than 150 mm (6 in.);
- Normal flowability: 150 to 200 mm (6 to 8 in.);
- High flowability: greater than 200 mm (8 in.)

ASTM C 939, for determining flow of grout, has been used successfully with fluid mixtures containing aggregates not greater than 6 mm (1/4 in.) The method is briefly described in Chapter 7 on Quality Control. The Florida and Indiana Departments of Transportation (DOT) require an efflux time of 30 ± 5 sec, as measured by this method.

4.2.2 *Segregation*—Separation of constituents in the mixture can occur at high levels of flowability when the flowability is primarily produced by the addition of water. This situation is similar to segregation experienced with some high-slump concrete mixtures. With proper mixture proportioning and materials, a high degree of flowability can be attained without segregation. For highly flowable CLSM without segregation, adequate fines are required to provide suitable cohesiveness. Fly ash generally accounts for these fines, although silty or other noncohesive fines up to 20% of total aggregate have been used. The use of plastic fines, such as clay, should be avoided because they can produce deleterious results, such as increased shrinkage. In flowable mixtures, satisfactory performance of CLSM has been obtained with Class F fly ash contents as high as 415 kg/m^3 (700 lb/yd^3) in combination with cement, sand, and water. Some CLSM mixtures have been designed without sand or gravel, using only fly ash as filler material. These mixtures require much higher water content, but produce no noticeable segregation.

4.2.3 *Subsidence*—Subsidence deals with the reduction in volume of CLSM as it releases its water and entrapped air through consolidation of the mixture. Water used for flowability in excess of that needed for hydration is generally absorbed by the surrounding soil or released to the surface as bleed water. Most of the subsidence occurs during placement and the degree of subsidence is dependent upon the quantity of free water released. Typically, subsidence of 3 to 6 mm (1/8 to 1/4 in.) per ft of depth has been reported.[34] This amount is generally found with mixtures of high water content. Mixtures of lower water content undergo little or no subsidence, and cylinder specimens taken for strength evaluation exhibited no measurable change in height from the time of filling the cylinders to the time of testing.

4.2.4 *Hardening time*—Hardening time is the approximate period of time required for CLSM to go from the plastic state to a hardened state with sufficient strength to support the weight of a person. This time is greatly influenced by the amount and rate of bleed water released. When this excess water leaves the mixture, solid particles realign into intimate contact and the mixture becomes rigid. Hardening time is greatly dependent on the type and quantity of cementitious material in the CLSM.

Normal factors affecting the hardening time are:

- Type and quantity of cementitious material;
- Permeability and degree of saturation of surrounding soil that is in contact with CLSM;
- Moisture content of CLSM;
- Proportioning of CLSM;
- Mixture and ambient temperature;
- Humidity; and
- Depth of fill.

Hardening time can be as short as 1 hr, but generally takes 3 to 5 hr under normal conditions.[4,25,34] A penetration-resistance test according to ASTM C 403 can be used to measure the hardening time or approximate bearing capacity of CLSM. Depending upon the application, penetration numbers of 500 to 1500 are normally required to assure adequate bearing capacity.[35]

4.2.5 *Pumping*—CLSM can be successfully delivered by conventional concrete pumping equipment. As with concrete, proportioning of the mixture is critical. Voids must be adequately filled with solid particles to provide adequate cohesiveness for transport through the pump line under pressure without segregation. Inadequate void filling results in mixtures that can segregate in the pump and cause line blockage. Also, it is important to maintain a continuous flow through the pump line. Interrupted flow can cause segregation, which also could restrict flow and could result in line blockage.

In one example, CLSM using unwashed aggregate with a high fines content was pumped through a 127 mm (5 in.) pump system at a rate of 46 m^3/hr (60 yd^3/hr).[36] In another example, CLSM with a slump as low as 51 mm (2 in.) was successfully delivered by concrete pump without the need for added consolidation effort.[37]

CLSM with high entrained-air contents can be pumped, although care should be taken to keep pump pressures low. Increased pump pressures can cause a loss in air content and reduce pumpability.

Pumpability can be enhanced by careful proportioning to provide adequate void filling in the mixture. Fly ash can aid pumpability by acting as microaggregate for void filling. Cement can also be added for this purpose. Whenever cementitious materials are added, however, care must be taken to limit the maximum strength levels if later excavation is a consideration.

4.3—In-service properties

4.3.1 *Strength (bearing capacity)*—Unconfined compressive strength is a measure of the load-carrying ability of CLSM. A CLSM compressive strength of 0.3 to 0.7 MPa (50

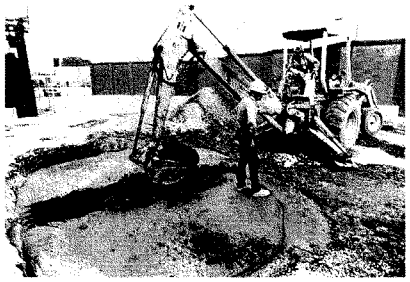

Fig. 4.1—Excavating CLSM with backhoe.

to 100 psi) equates to an allowable bearing capacity of a well-compacted soil.

Maintaining strengths at a low level is a major objective for projects where later excavation is required. Some mixtures that are acceptable at early ages continue to gain strength with time, making future excavation difficult. Section 4.3.7 provides additional information on excavatability.

4.3.2 *Density*—Wet density of normal CLSM in place is in the range of 1840 to 2320 kg/m^3 (115 to 145 lb/ft^3), which is greater than most compacted materials. A CLSM mixture with only fly ash, cement, and water should have a density between 1440 to 1600 kg/m^3 (90 to 100 lb/ft^3).[12] Ponded ash or basin ash CLSM mixture densities are typically in the range of 1360 to 1760 kg/m^3 (85 to 110 lb/ft^3).[19] Dry density of CLSM can be expected to be substantially less than that of the wet density due to water loss. Lower unit weights can be achieved by using lightweight aggregates, high entrained-air contents, and foamed mixtures, which are discussed in detail in Chapter 8.

4.3.3 *Settlement*—Compacted fills can settle even when compaction requirements have been met. In contrast, CLSM does not settle after hardening. Measurements taken months after placement of a large CLSM fill showed no measurable shrinkage or settlement.[13] For a project in Seattle, Wash., 601 m^3 (786 yd^3) were used to fill a 37 m (120 ft) deep shaft. The placement took 4 hr and the total settlement was reported to be about 3 mm (1/8 in.).[37]

4.3.4 *Thermal insulation/conductivity*—Conventional CLSM mixtures are not considered good insulating materials. Air-entrained conventional mixtures reduce the density and increase the insulating value. Lightweight aggregates, including bottom ash, can be used to reduce density. Foamed or cellular mixtures as described in Chapter 8 have low densities and exhibit good insulating properties.

Where high thermal conductivity is desired, such as in backfill for underground power cables, high density and low porosity (maximum surface contact area between solid particles) are desirable. As the moisture content and dry density increase, so does the thermal conductivity. Other parameters to consider (but of lesser importance) include mineral composition, particle shape and size, gradation characteristics, organic content and specific gravity.[31,38-40]

4.3.5 *Permeability*—Permeability of most excavatable CLSM is similar to compacted granular fills. Typical values are in the range of 10^{-4} to 10^{-5} cm/sec. Mixtures of CLSM with higher strength and higher fines-content can achieve permeabilities as low as 10^{-7} cm/sec. Permeability is increased as cementitious materials are reduced and aggregate contents are increased.[4] However, materials normally used for reducing permeability, such as bentonite clay and diatomaceous soil, can affect other properties and should be tested prior to use.

4.3.6 *Shrinkage (cracking)*—Shrinkage and shrinkage cracks do not affect the performance of CLSM. Several reports have indicated that minute shrinkage occurs with CLSM. Ultimate linear shrinkage is in the range of 0.02 to 0.05%.[12,27,34]

4.3.7 *Excavatability*—The ability to excavate CLSM is an important consideration on many projects. In general, CLSM with a compressive strength of 0.3 MPa (50 psi) or less can be excavated manually. Mechanical equipment, such as backhoes, are used for compressive strengths of 0.7 to 1.4 MPa (100 to 200 psi) (Fig. 4.1). The limits for excavatability are somewhat arbitrary, depending upon the CLSM mixture. Mixtures using high quantities of coarse aggregate can be difficult to remove by hand, even at low strengths. Mixtures using fine sand or only fly ash as the aggregate filler have been excavated with a backhoe up to strengths of 2.1 MPa (300 psi).[11]

When the re-excavatability of the CLSM is of concern, the type and quantity of cementitious materials is important. Acceptable long-term performance has been achieved with cement contents from 24 to 59 kg/m^3 (40 to 100 lb/yd^3) and Class F fly ash contents up to 208 kg/m^3 (350 lb/yd^3). Lime (CaO) contents of fly ash that exceed 10% by weight can be a concern where long-term strength increases are not desired.[27]

Because CLSM will typically continue to gain strength beyond the conventional 28-day testing period, it is suggested, especially for high cementitious-content CLSM, that long-term strength tests be conducted to estimate the potential for re-excavatability.

In addition to limiting the cementitious content, entrained air can be used to keep compressive strengths low.

4.3.8 *Shear modulus*—The shear modulus, which is the ratio of unit shearing stress to unit shearing strain, of normal density CLSM is typically in the range of 160 to 380 MPa (3400 to 7900 ksf).[7,18,20] The shear modulus is used to evaluate the expected shear strength and deformation of CLSM material.

4.3.9 *Potential for corrosion*—The potential for corrosion on metals encased in CLSM has been quantified by a variety of methods specific to the material that is in contact with CLSM. Electrical resistivity tests can be performed on CLSM in the same manner that natural soils are compared for their corrosion potential on corrugated metal culvert pipes (California Test 643). The moisture content of the sample is an important parameter for the resistivity of a sample, and the samples should be tested at their expected long-term field moisture content.

The Ductile Iron Pipe Research Association has a method for evaluating the corrosion potential of backfill materials. The evaluation procedure is based upon information drawn from five tests and observations: soil resistivity; pH; oxidation-reduction (redox) potential; sulfides; and moisture. For a given sample, each parameter is evaluated and assigned points according to its contribution to corrosivity.[41-43]

These procedures are intended as guides in determining a soil's potential corrosivity to ductile iron pipe and should be used only by qualified engineers and technicians experienced in soil analysis and evaluation.

One cause of galvanic corrosion is the differences in potential from backfill soils of varying composition. The uniformity of CLSM reduces the chance for corrosion caused by the use of dissimilar backfill materials and their varying moisture contents.

4.3.10 *Compatibility with plastics*—High-, medium-, and low-density polyethylene materials are commonly used as protection for underground utilities or as the conduits themselves. CLSM is compatible with these materials. As with any backfill, care must be exercised to avoid damaging the protective coating of buried utility lines. The fine gradation of many CLSMs can aid in minimizing scratching and nicking these polyethylene surfaces.[31]

CHAPTER 5—MIXTURE PROPORTIONING

Proportioning for CLSM has been done largely by trial and error until mixtures with suitable properties are achieved. Most specifications require proportioning of ingredients; some specifications call for performance features and leave proportioning up to the supplier. ACI 211 has been used; however, much work remains to be done in establishing consistent reliability when using this method.[37]

Where proportions are not specified, trial mixtures are evaluated to determine how well they meet certain goals for strength, flowability, and density. Adjustments are then made to achieve the desired properties.

Table 5.1 presents a number of mixture proportions that have been used by state DOTs and others; however, requirements and available materials can vary considerably from project to project. Therefore, the information in Table 5.1 is provided as a guide and should not be used for design purposes without first testing with locally available materials.

The following summary can be made regarding the materials used to manufacture CLSM:

Cement—Cement contents generally range from 30 to 120 kg/m^3 (50 to 200 lb/yd^3), depending upon strength and hardening-time requirements. Increasing cement content while maintaining all other factors equal (that is, water, fly ash, aggregate, and ambient temperature) will normally increase strength and reduce hardening time.

Fly ash—Class F fly ash contents range from none to as high as 1200 kg/m^3 (2000 lb/yd^3) where fly ash serves as the aggregate filler. Class C fly ash is used in quantities of up to 210 kg/m^3 (350 lb/yd^3). The quantity of fly ash used will be determined by availability and flowability needs of the project.

Ponded ash/basin ash—Ponded ash/basin ash contents range from 300 to 500 kg/m^3 (500 to 950 lb/yd^3), depending upon the fineness of ash.[18-20]

Aggregate—The majority of specifications call for the use of fine aggregate. The amount of fine aggregate varies with the quantity needed to fill the volume of the CLSM after considering cement, fly ash, water, and air contents. In general, the quantities range from 1500 to 1800 kg/m^3 (2600 to 3100 lb/yd^3). Coarse aggregate is generally not used in CLSM mixtures as often as fine aggregates. When used, however, the coarse aggregate content is approximately equal to the fine aggregate content.

Water—More water is used in CLSM than in concrete. Water provides high fluidity and promotes consolidation of the materials. Water contents typically range from 193 to 344 kg/m^3 (325 to 580 lb/yd^3) for most CLSM mixtures containing aggregate. Water content for Class F fly ash and cement-only mixtures can be as high as 590 kg/m^3 (1000 lb/yd^3) to achieve good flowability. This wide range is due primarily to the characteristics of the materials used in CLSM and the degree of flowability desired. Water contents will be higher with mixtures using finer aggregates.

Admixtures—High doses of air-entraining admixtures and specifically formulated or packaged air-entraining admixtures, or both, can be used to lower the density or unit weight of CLSM. Accelerating admixtures can be used to accelerate the hardening of CLSM. When these products are used, the manufacturer's recommendations for use with CLSM should be followed.

Other additives—Additives such as zeolites, heavy minerals, and clays can be added to typical CLSM mixes in the range of 2 to 10% of the total mixture. Fly ash and cement can be adjusted accordingly while maintaining all other factors.[18-20]

CHAPTER 6—MIXING, TRANSPORTING, AND PLACING

6.1—General

The mixing, transporting, and placing of CLSM generally follows methods and procedures given in ACI 304. Other methods can be acceptable, however, if prior experience and performance data are available. Whatever methods and procedures are used, the main criteria is that the CLSM be homogeneous, consistent, and satisfy the requirements for the purpose intended.

6.2—Mixing

CLSM can be mixed by several methods, including central-mixed concrete plants, ready-mixed concrete trucks, pugmills, and volumetric mobile concrete mixers. For high fly ash mixtures where fly ash is delivered to the mixer from existing silos, batching operations can be slow.

Truck mixers are commonly used by ready-mixed concrete producers to mix CLSM; however, in-plant central mixers can be used as well. In truck-mixing operations, the following is one procedure that can be used for charging truck mixers with batch materials.

Table 5.1—Examples of CLSM mixture proportions*

Source	CO DOT	IA DOT	FL DOT	IL DOT	IN DOT		OK DOT	MI DOT		OH DOT	
					Mix 1	Mix 2[4]		Mix 1	Mix 2[4]	Mix 1	Mix 2
Cement content, kg/m³	30 (50)	60 (100)	30 to 60 (50 to 100)	30 (50)	36 (60)	110 (185)	30 (50) min	60 (100)	30 (50)	60 (100)	30 (50)
Fly ash, kg/m³ (lb/yd³)	—	178 (300)	0 to 356 (0 to 600)[2]	178 (300) Class F or 119 (200) Class C	196 (330)	—	148 (250)	1187 (2000) Class F	326 (550) Class F	148 (250)	148 (250)
Coarse aggregate, kg/m³ (lb/yd³)	1010 (1700)[1]	—	—	—	—	—	—	—	Footnote no. 5	—	—
Fine aggregate, kg/m³ (lb/yd³)	1096 (1845)	1543 (2600)	1632 (2750)[3]	1720 (2900)	1697 (2860)	1587 (2675)	1727 (2910)	—	Footnote no. 5	1691 (2850)	1727 (2910)
Approximate water content, kg/m³ (lb/yd³)	193 (325)	347 (585)	297 (500) maximum	222 to 320 (375 to 540)	303 (510)	297 (500)	297 (500) maximum	395 (665)	196 (330)	297 (500)	297 (500)
Compressive strength at 28 days, MPa (psi)	0.4 (60)	—	0.3 to 1.0 (50 to 150)	—	—	—	—	—	—	—	—

Table 5.1(continued)—Examples of CLSM mixture proportions*

Source	SC DOT	DOE-SR[16]	Unshrinkable fill[6]	Pond ash/basin ash mix[17]		Coarse aggregate CLSM[8]		Flowable fly ash slurry[12]		
				Mix AF	Mix D	Non-air entrainment[9]	Air entrainment[11]	Mix S-2[13]	Mix S-3[14]	Mix S-4[15]
Cement content, kg/m³	30 (50)	30 (50)	36 (60)	98 (165)	60 (100)	30 (50)	30 (50)	58 (98)	94 (158)	85 (144)
Fly ash, kg/m³ (lb/yd³)	356 (600)	356 (600) Class F	—	481 (810)[18]	326 (550)[19]	148 (250)	148 (250)	810 (1366) Class F	749 (1262) Class F	685 (1155) Class F
Coarse aggregate, kg/m³ (lb/yd³)	—	—	1012 (1705) (3/4-in. maximum)	1300 (2190)	1492 (2515)	1127 (1900) (1-in. maximum)	1127 (1900) (1-in. maximum)	—	—	—
Fine aggregate, kg/m³ (lb/yd³)	1483 (2500)	1492 (2515)	1173 (1977)	—	—	863 (1454)	795 (1340)	—	—	—
Approximate water content, kg/m³ (lb/yd³)	273 to 320 (460 to 540)	397 to 326 (500 to 550)	152 (257)[7]	415 (700)	301 (507)	160 (270)[10]	151 (255)[10]	634 (1068)	624 (1052)	680 (1146)
Compressive strength at 28 days, MPa (psi)	0.6 (80)	0.2 to 1.0 (30 to 150)	0.1 (17) at 1 day	0.4 (65)	0.4 (65)	0.7 (100)	—	0.3 (40) (40 at 56 days)	0.4 (60) [0.5 (75) at 56 days]	0.3 (50) [0.5 (70) at 56 days]

*Table examples are based on experience and test results using local materials. Yields will vary from 0.76 m³ (27 ft³). This table is given as a guide and should not be used for design purposes without first testing with locally available materials.
[1]Quantity of cement can be increased above these limits only when early strength is required and future removal is unlikely.
[2]Granulated blast-furnace slag can be used in place of fly ash.
[3]Adjust to yield 1 yd³ of CLSM.
[4]5 to 6 fl oz of air-entraining admixture produces 7 to 12% air contents.
[5]Total granular material of 1690 kg/m³ (2850 lb/yd³) with 19 mm (3/4 in.) maximum aggregate size.
[6]Reference 44.
[7]Produces 150 mm (6 in.) slump.
[8]Reference 37.
[9]Produces approximately 1.5% air content.
[10]Produces 150 to 200 mm (6 to 8 in.) slump.
[11]Produces 5% air content.
[12]Reference 6.
[13]Produces modified flow of 210 mm (8-1/4 in.) diameter (Table 7.1); air content of 0.8%; slurry density of 1500 kg/m³ (93.7 lb/ft³).
[14]Produces modified flow of 270 mm (10-1/2 in.) diameter; air content of 1.1%; slurry density of 1470 kg/m³ (91.5 lb/ft³).
[15]Produces modified flow of 430 mm (16-3/4 in.) diameter; air content of 0.6%; slurry density of 1450 kg/m³ (90.6 lb/ft³).
[16]Department of Energy (DOE) Savannah River Site CLSM mix.
[17]DOE Savannah River Site CLSM mix using pond/basin ash.
[18]Basin ash mix.
[19]Pond ash mix.

Load truck mixer at standard charging speed in the following sequence:

- Add 70 to 80% of water required.
- Add 50% of the aggregate filler.
- Add all cement and fly ash required.
- Add balance of aggregate filler.
- Add balance of water.

For CLSM mixtures consisting of fly ash, cement, water, and no aggregate filler, an effective mixing method consists of initially charging the truck mixer with cement then water. After thoroughly mixing these materials, the fly ash is added. Additional mixing for a minimum of 15 min was required in one case to produce a homogeneous slurry.[12]

Pugmill mixing works efficiently for both high and low fly ash mixtures and other high fines-content mixtures. For high fly ash mixtures, the fly ash is fed into a hopper with a front-end loader, which supplies a belt conveyor under the hopper. This method of feeding the mixer is much faster than silo

feed. To prevent bridging within the fly ash, a mechanical agitator or vibrator is used in the hopper. Cement is usually added to the mixer by conveyor from silo storage. If bagged cement is used, it is added directly into the mixer. The measurement for payment of CLSM mixed through a pugmill is generally based on weight rather than volume, which is typically used for concrete.

6.3—Transporting

Most CLSM mixtures are transported in truck mixers. Agitation of CLSM is required during transportation and waiting time to keep the material in suspension. Under certain on-site circumstances, CLSM has been transported in nonagitating equipment such as dump trucks. Agitator trucks, although providing some mixing action, may not provide enough action to prevent the solid materials from settling out.

CLSM has been transported effectively by pumps and other types of conveying equipment. In pumping CLSM, the fly ash serves as a lubricant to reduce the friction in the pipeline. However, the fine texture of the fly ash requires that the pump be in excellent condition and properly cleaned and maintained.

CLSM has also been transported effectively by volumetric-measuring and continuous-mixing concrete equipment (VMCM) (ACI 304.6R), particularly if it is desired to reduce waiting time. The major advantage of this equipment is its ability to mix at the job site and vary the water content to attain desired flowability. This is particularly true for fast-setting CLSM mixtures. VMCMs are equipped with separate bins for water, cementitious materials, and selected aggregates. The materials are transported to the job site where continuous mixing of water and dry materials make a good, easily regulated CLSM.

6.4—Placing

CLSM can be placed by chutes, conveyors, buckets, or pumps, depending upon the application and its accessibility. Internal vibration or compaction is not required because the CLSM consolidates under its own weight. Although it can be placed year round, CLSM should be protected from freezing until it has hardened. Curing methods specified for concrete are not considered essential for CLSM.[27]

For trench backfill, CLSM is usually placed continuously. To contain CLSM when filling long, open trenches in stages or open-ended structures such as tunnels, the end points can be bulkheaded with sandbags, earth dams, or stiffer mixtures of CLSM.

For pipe bedding, CLSM can be placed in lifts to prevent floating the pipe. Each lift should be allowed to harden before continued placement. Other methods of preventing flotation include sand bags placed over the pipe, straps around the pipe anchored into the soil, or use of faster-setting CLSM placed at strategic locations over the pipe.

In the plastic state, CLSM is not self-supporting and places a load on the pipe. For large, flexible wall pipes, CLSM should be placed in lifts so that lateral support can develop along the side of the pipe before fresh CLSM is placed over the pipe.[4] Backfilling retaining walls can also require the CLSM be placed in lifts to prevent overstressing the wall.

CLSM has been effectively placed by tremie under water[11] without significant segregation. In confined areas, the CLSM displaces the water to the surface where it can easily be removed. Because of its very fluid consistency, CLSM can flow long distances to fill voids and cavities located in hard-to-reach places. Voids need not be cleaned, as the slurry will fill in irregularities and encapsulate any loose materials.

6.5—Cautions

6.5.1 *Hydrostatic pressure*—CLSM is often placed in a practically liquid condition and thus will exert a hydrostatic pressure against basement walls and other structures until it hardens. On deep fills, it is often necessary to place the CLSM in multiple lifts.

6.5.2 *Quick condition*—Liquid CLSM in deep excavations is essentially a quick-sand hazard and therefore should be covered until hardening occurs.

6.5.3 *Floating tanks, pipes, and cables*—Underground utilities and tanks must be secured against floating during CLSM placement.[45]

CHAPTER 7—QUALITY CONTROL

7.1—General

The extent of a quality-control (QC) program for CLSM can vary depending upon previous experience, application, raw materials used, and level of quality desired. A QC program can be as simple as a visual check of the completed work where standard, pretested mixtures are being used. Where the application is critical, the materials are nonstandard, or where product uniformity is questionable, regular tests for consistency and strength may be appropriate.

Both as-mixed and in-service properties can be measured to evaluate the mixture consistency and performance. For most projects, CLSM is pretested using the actual raw materials to develop a mixture having certain plastic (flowability, consistency, unit weight) and hardened (strength, durability, permeability) characteristics. Following the initial testing program, field testing can consist of simple visual checks, or can include consistency measurements or compressive strength tests.

As stated above, the QC program can be simple or detailed. It is the responsibility of the specifier to determine an appropriate QC program that will assure that the product will be adequate for its intended use. The following procedures and test methods have been used to evaluate CLSM mixtures.

7.2 Sampling

Sampling CLSM that has been delivered to the project site should be performed in accordance with ASTM D 5971.

7.3—Consistency and unit weight

Depending upon application and placement requirements, flow characteristics can be important. CLSM consistency can vary considerably from plastic to fluid; therefore, several methods of measurement are available. Most CLSM mixtures perform well with various flow and unit weight proper-

Table 7.1—Test procedures for determining consistency and unit weight of CLSM mixtures

Consistency	
Fluid mixtures	
ASTM D 6103	"Standard Test Method for Flow Consistency of Controlled Low Strength Material." Procedure consists of placing 75 mm diameter x 150 mm long (3 in. diameter x 6 in. long) open-ended cylinder vertically on level surface and filling cylinder to top with CLSM. Cylinder is then lifted vertically to allow material to flow out onto level surface. Good flowability is achieved where there is no noticeable segregation and material spread is at least 200 mm (8 in.) in diameter.
ASTM C 939	"Flow of Grout for Preplaced-Aggregate Concrete." Florida Department of Transportation and Indiana Department of Transportation specifications require efflux time of 30 sec ±5 sec. Procedure is not recommended for CLSM mixtures containing aggregates greater than 6 mm (1/4 in.).
Plastic mixtures	
ASTM C 143	"Slump of Portland Cement Concrete."
Unit weight	
ASTM D 6023	"Standard Test Method for Unit Weight, Yield and Air Content (Gravimetric) of Controlled Low Strength Material." Ohio Ready Mixed Concrete Association has similar test method [FF3(94)].
ASTM C 1152	"Acid Soluble Chloride in Mortar and Concrete."
ASTM D 4380	"Density of Bentonitic Slurries." Not recommended for CLSM containing aggregate greater than 1/4 in.
ASTM D 1556	"Density of Soil In-Place by Sand-Cone Method."
ASTM D 2922	"Density of Soil and Soil Aggregate In-Place by Nuclear Method (Shallow Depth)."

Table 7.2—Test procedures for determining in-place density and strength of CLSM mixtures

ASTM D 6024	"Standard Test Method for Ball Drop on Controlled Low Strength Material to Determine Suitability for Load Application." This specification covers determination of ability of CLSM to withstand loading by repeatedly dropping metal weight onto in-place material.
ASTM C 403	"Time of Setting of Concrete Mixtures by Penetration Resistance." This test measures degree of hardness of CLSM. California Department of Transportation requires penetration number of 650 before allowing pavement surface to be placed.
ASTM D 4832	"Preparation and Testing of Soil-Cement Slurry Test Cylinders." This test is used for molding cylinders and determining compressive strength of hardened CLSM.
ASTM D 1196	"Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements." This test is used to determine modulus of subgrade reaction (K values).
ASTM D 4429	"Bearing Ratio of Soils in Place." This test is used to determine relative strength of CLSM in place.

ties. Table 7.1 describes methods that can be used to measure consistency and unit weight.

7.4—Strength tests

CLSM is used in a variety of applications requiring different load-carrying characteristics. The maximum loads to be imposed on the CLSM should be identified to determine the minimum strength requirements. In many cases, however, CLSM needs to be limited in its maximum strength. This is especially true where removal of the material at a later date is anticipated.

The strength of CLSM can be measured by several methods (Table 7.2). Unconfined compressive strength tests are the most common; however, other methods, such as penetrometer devices or plate load tests, can also be used. Compressive-strength specimens can vary in size from 50 x 50 mm (2 x 2 in.) cubes to 150 x 300 mm (6 x 12 in.) cylinders. Special care may be needed removing very low-strength CLSM mixtures from test molds. Additional care in the handling, transporting, capping, and testing procedures shall be taken because the specimens are often very fragile. Mold stripping techniques have included: placement of a hole on the center of the bottom of standard watertight cylinder molds by drilling or use of a hot probe, and addition of a dry polyester fleece pad on the inside bottom of the cylinder; for easy release of the specimen with or without air compression, splitting of the molds with a hot knife, and presplitting the molds and reattachment with duct tape for easy removal later. The use of grout molds has also been employed for testing CLSM. In this method, four 150 x 150 x 200 mm (6 x 6 x 8 in.) high concrete masonry units are arranged to provide a nominal 100 mm (4 in.) square space in the center. The four sides and bottom of the inside of the molds are lined with blotting paper to serve as a bond breacher for easy removal.

CHAPTER 8—LOW-DENSITY CLSM USING PREFORMED FOAM

8.1—General

This chapter is limited to low-density CLSM mixtures (LD-CLSM) produced using preformed foam as part of the mixture proportioning. Preformed foam is made up of air cells generated from foam concentrates or gas-forming

chemicals. The use of preformed foam in LD-CLSM mixtures allows mixture proportionings to be developed having lower unit weights than those typical of standard CLSM mixtures. Preformed foam is used in LD-CLSM proportions to attain stable air void or cell structures within the paste of the mix. LD-CLSM mixtures can be batched at ready-mix plants or in specially designed job site batch plants. The preformed foam can be added to LD-CLSM mixtures during batching at the ready-mix plant, into the mixers of transit-mix trucks at the job site, or directly into the mixer during the batching operations of specially designed job site batch plants.

8.2—Applications

LD-CLSM mixtures can be alternatively considered in situations where standard CLSM mixtures have been determined applicable. LD-CLSMs are typically designed by unit weight. The ability to proportion mixtures having low unit weights is especially advantageous where weak soil conditions are encountered and the weight of the fill must be minimized. LD-CLSM is also effective as an insulating and isolation fill. The air void or cell structure inherent in LD-CLSM mixtures provides thermal insulation and can add some shock mitigation properties to the fill material.

8.3—Materials

Portland cement is a typical binder component used to produce most LD-CLSM mixtures. Neat cement paste LD-CLSMs can be produced by adding preformed foam to the paste during mixing. The encapsulated air within the preformed foam is often the primary volume-producing component in the LD-CLSM mixtures. LD-CLSMs can also be designed to include mineral fillers such as fly ash or sand. When considering the use of nonstandard binders or mineral filler materials in LD-CLSM mixture proportioning, pretesting is recommended.

Generally all preformed foams are pregenerated by the use of devices known as foam generators. These foam-generating devices, however, can be configured specifically to be used with a particular foaming agent. The manufacturer of the foaming agent to be used should be consulted to obtain specific foam-generating recommendations.

Foaming agents used to produce the preformed foam must have a chemical composition capable of producing stable air cells that resist the physical and chemical forces imposed during the mixing, placing, and setting of the LD-CLSM mixture. If the air void or cellular structure within the mixture is not stable, a nonuniform increase in density will result. Procedures for the evaluation of foaming agents are specified in ASTM C 796 and ASTM C 869. Additional information can be found in ACI 523.1R.

8.4—Properties

The properties of LD-CLSM are primarily density-related. When batched using standard component materials, LD-CLSM can be produced having properties that fall within ranges described by the manufacturer of the foaming agent. When nonstandard component materials are used, trial batches should be produced and tested to confirm theoretical predictions.

Table 8.1—Typical strength properties of low-density CLSM based on density

Class	In-service density, kg/m^3 (lb/ft^3)	Minimum compressive strength, MPa (psi)
I	290 to 380 (18 to 24)	0.1 (10)
II	380 to 480 (24 to 30)	0.3 (40)
III	480 to 580 (30 to 36)	0.6 (80)
IV	580 to 670 (36 to 42)	0.8 (120)
V	670 to 800 (42 to 50)	1.1 (160)
VI	800 to 1300 (50 to 80)	2.2 (320)
VII	1300 to 1900 (80 to 120)	3.4 (500)

The most significant property of LD-CLSM is the in-service density. Table 8.1 divides the in-service density into convenient ranges relating density with typical minimum compressive-strength values. Classes VI and VII may be subdivided into smaller ranges for specific applications.

8.5—Proportioning

Mixture proportioning of LD-CLSM typically begins with the designation of the desired in-place dry density and minimum compressive strength. Within these parameters, the mixture constituents are designed on a rational basis. Basic LD-CLSM mixtures consist of portland cement as a binder, water, and preformed foam. In addition to this base proportioning, fly ash can be included as a pozzolan or a densifying mineral filler. Sand aggregate is also often used to achieve density in mixture proportionings having unit weights more than 800 kg/m^3 (50 lb/ft^3). The manufacturer of the foam concentrate is generally responsible for the mixture proportioning, which is based on desired physical properties (density, compressive strength, etc.) of the in-place material.

8.6—Construction

8.6.1 *Batching*—The batching sequence used to produce most LD-CLSM mixtures begins by metering the required water into a mechanical mixer. The portland cement binder, fly ash, or aggregates (if used) are individually weighed before entering the mixer. After the components are mixed to a uniform consistency, the required amount of preformed foam is added. The preformed foam is measured into the mixture through calibrated nozzle or by filling and weighing a mixing vessel of known volume. The accuracy of the foam-generating device and the batching apparatus is critical to the final mixture's density and its subsequent reproducibility.

8.6.2 *Mixing*—All LD-CLSM component materials should be mechanically mixed to a uniform consistency prior to the addition of the preformed foam. To properly combine the mixture ingredients (including the foam) sufficient mixing action and speeds are required. When producing neat cement or cement/fly ash pastes for LD-CLSM mixtures, mixers that provide vigorous mixing action, such as high-speed paddle mixers, are preferred. Truck mixers readily blend LD-CLSM mixtures to the consistency required for the addition of preformed foam. When truck mixers are used to produce neat

cement or cement/fly ash paste mixtures, slightly longer mixing times are required. Other mixing processes, such as volumetric mixing, that produce uniformly consistent mixtures are also acceptable. The manufacturer of the foaming agent to be used should be consulted for specific recommendations on mixing procedures and approved mixing equipment.

8.6.3 *Placing*—LD-CLSM can be placed by chutes, buckets, or pumps. The method of placement must not cause a change in density by loss of air content beyond predictable ranges. Often, site-produced LD-CLSMs are delivered to the point of placement through pumplines. Progressing cavity pumps can be used, which provide nonpulsating and constant flow, minimizing air volume losses between the mixer and the point of deposit. By this method, LD-CLSMs can be pumped over 300 m (1000 ft).

CONVERSION FACTORS

1 ft	=	0.305 m
1 in.	=	25.4 mm
1 lb	=	0.454 kg
1 yd^3	=	0.7646 m^3
1 psi	=	6.895 kPa
1 lb/ft^3	=	16.02 kg/m^3
1 lb/yd^3	=	0.5933 kg/m^3
1 ft/sec	=	0.305 m/sec

CHAPTER 9—REFERENCES

9.1—Specified references

The documents of the various standard-producing organizations referred to in this document are listed below with their serial designation.

American Concrete Institute

116R Cement and Concrete Terminology
211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete
230.1R State-of-the-Art Report on Soil Cement
232.2R Use of Fly Ash in Concrete
304.6R Guide for Measuring, Mixing, Transporting and Placing Concrete
325.3R Guide for Design of Foundations and Shoulders for Concrete Pavements
523.1R Guide for Cast-in-Place Low Density Concrete

American Society for Testing and Materials (ASTM)

C 33 Specification for Concrete Aggregates
C 94 Specifications for Ready-Mixed Concrete
C 138 Test Method for Unit Weight, Yield and Air Content (Gravimetric) of Concrete
C 143 Test Method for Slump of Hydraulic Cement Concrete
C 150 Specification for Portland Cement
C 403 Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
C 595 Specification for Blended Hydraulic Cements
C 618 Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
C 796 Test Method of Testing Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam
C 869 Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete
C 939 Test Method for Flow of Grout for Preplaced-Aggregate Concrete
C 1152 Acid-Soluble Chloride in Mortar and Concrete
C 1556 Density of Soil in-place by Sand-cone Method
C 2922 Density of Soil and Soil Aggregate in-place by Nuclear Method (Shallow Depth)
D 1196 Test Methods for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements
D 4380 Test Method for Density of Bentonitic Slurries
D 4429 Test Method for Bearing Ratio of Soils in Place
D 4832 Test Method for Preparation and Testing of Soil-Cement Slurry Test Cylinders
D 5971 Practice for Sampling Freshly Mixed Controlled Low Strength Material
D 6023 Test Method for Unit Weight, Yield and Air Content (Gravimetric) of Controlled Low Strength Material
D 6024 Test Method of Ball Drop on Controlled Low Strength Material to Determine Suitability for Load Application
D 6103 Test Method for Flow Consistency of Controlled Low Strength Material

The above publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

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ACI 232.2R-03

Use of Fly Ash in Concrete

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Fly ash is used in concrete and other cement-based systems primarily because of its pozzolanic and cementitious properties. These properties contribute to strength gain and may improve the performance of fresh and hardened concrete, mortar, and grout. The use of fly ash may result in more economical concrete construction.

This report gives an overview of the origin and properties of fly ash, its effect on the properties of hydraulic cement concrete, and the proper selection and use of fly ash in the production of hydraulic cement concrete and concrete products. Information and recommendations concerning the selection and use of Class C and Class F fly ashes generally conforming to the requirements of ASTM C 618 are provided. Topics covered include a detailed description of the composition of fly ash, the physical and chemical effects of fly ash on properties of concrete, guidance on the handling and use of fly ash in concrete construction, use of fly ash in the production of concrete products and specialty concrete, and recommended procedures for quality control. Relevant documents of standards-making bodies referred to in this document are cited and listed.

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Keywords: abrasion resistance; admixture; alkali-aggregate reaction; concrete pavement; controlled low-strength material; drying shrinkage; durability; efflorescence; fineness; fly ash; hydraulic cement; mass concrete; mixture proportion; pozzolan; precast concrete; quality control; reinforced concrete; roller-compacted concrete; soil cement; strength; sulfate resistance; workability.

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CHAPTER 1—GENERAL

1.1—Introduction

Fly ash, a by-product from the combustion of pulverized coal, is widely used as a cementitious and pozzolanic ingredient in hydraulic cement concrete. Because it improves many desirable properties of concrete, it is introduced either as a separately batched material (as in ASTM C 618, Class F or C) or as a component of blended cement (ASTM C 595 or C 1157).

This report describes the use of fly ash in concrete and lists references concerning the characterization of fly ash, its properties, and its effects on concrete. Guidance is provided concerning specifications, quality assurance and quality control of fly ash, and concrete produced using fly ash.

According to ACI 116R, fly ash is "the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases from the combustion zone to the particle removal system." ACI 116R defines "pozzolan" as "a siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value but that will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds having cementitious properties; there are both natural and artificial pozzolans." Fly ash possesses pozzolanic properties similar to the naturally occurring pozzolans of volcanic or sedimentary origin found in many parts of the world. About 2000 years ago, the Romans mixed volcanic ash with lime, aggregate, and water to produce mortar and concrete (Vitruvius 1960). Similarly, fly ash is mixed with portland cement (which releases lime during hydration), aggregate, and water to produce mortar and concrete.

All fly ashes exhibit pozzolanic properties to some extent; however, some fly ashes display varying degrees of cementitious value without the addition of calcium hydroxide or hydraulic cement. The cementitious nature of these fly ashes is attributed to reactive constituents

that reside within the fly ash, such as crystalline, calcium aluminate phases, and a more highly substituted, and therefore, potentially reactive glass phase. Fly ash in concrete reacts with the hydrating hydraulic cement in the following ways:

1. Solutions of calcium and alkali hydroxide, which are released into the pore structure of the paste, combine with the pozzolanic particles of fly ash, forming a cementing medium; and

2. Heat generated by hydration of hydraulic cement helps initiate the pozzolanic reaction and contributes to the rate of the reaction.

When concrete containing fly ash is properly cured, fly-ash reaction products partially fill in the spaces originally occupied by mixing water that were not filled by the hydration products of the cement, thus lowering the concrete permeability to water and aggressive chemicals (Manmohan and Mehta 1981). The slower reaction rate of fly ash, when compared to hydraulic cement, limits the amount of early heat generation and the detrimental early temperature rise in massive structures. Concrete proportioned with fly ash can have properties that are not achievable through the use of hydraulic cement alone.

Fly ash from coal-burning electric power plants became readily available in the 1930s. In the U.S., the study of fly ash for use in hydraulic cement concrete began at about that time. In 1937, results of research on concrete containing fly ash were published (Davis et al. 1937). This work served as the foundation for early specifications, methods of testing, and use of fly ash.

Initially, fly ash was used as a partial mass or volume replacement of hydraulic cement, typically the most expensive manufactured component of concrete. As fly ash usage increased, researchers recognized that fly ash could impart beneficial properties to concrete. In subsequent research, Davis and colleagues studied the reactivity of fly ash with calcium and alkali hydroxides in portland-cement paste and the ability of fly ash to act as a preventive measure against deleterious alkali-aggregate reactions. Research (Dunstan 1976, 1980; Tikalsky, Carrasquillo, and Snow 1992; Tikalsky and Carrasquillo 1993) has shown that fly ash often improves the concrete's resistance to deterioration from sulfates. Fly ash also increases the workability of fresh concrete and reduces the peak temperature of hydration in mass concrete. The beneficial aspects of fly ash were especially notable in the construction of large concrete dams (Mielenz 1983). Some major projects, including the Thames Barrage in the UK and the Upper Stillwater Dam in the U.S., incorporated 30 to 75% mass replacement of hydraulic cement by fly ash to reduce heat generation and decrease permeability.

In the U.S., a new generation of coal-fired power plants was built during the late 1960s and 1970s, at least partially in response to dramatically increased oil prices. These power plants, using efficient coal mills and state-of-the-art pyroprocessing technology, produce finer fly ashes with a lower carbon content. In addition, fly ash containing high levels of calcium oxide became available due to the use of western U.S. coal sources (typically sub-bituminous and lignitic). Concurrent with this increased availability of fly ash, extensive research has led to a better understanding of the chemical reactions involved when fly ash is used in concrete. Enhanced economics and improved technologies (material- and mechanical-based) have led to a greater use of fly ash, principally in the ready-mix concrete industry. Fly ash is now used in concrete for many reasons, including improvements in workability of fresh concrete, reduction in temperature rise during initial hydration, improved resistance to sulfates, reduced expansion due to alkali-silica reaction, and contributions to the durability and strength of hardened concrete.

1.2—Source of fly ash

Due to the increased use of pulverized coal as fuel for electric power generation, fly ash is now available in many areas of the world. Fly ash is a by-product of burning coals that have been crushed and ground to a fineness of 70 to 80% passing a 75 μm (No. 200 [0.0030 in.]) sieve. Approximately 57,000 Gg (63 million tons) of fly ash is produced annually in the U.S. (American Coal Ash Association 2000). An estimated 18 to 20% of that total is used in the production of concrete and concrete products. ASTM C 618 categorizes fly ash by chemical composition, according to the sum of the iron, aluminum, and silicon content (expressed in oxide form). As a group, Class F and C ashes generally show different performance characteristics; however, the performance of a fly ash is not determined solely by its classification. Class F ashes are normally produced from coals with higher heat energy such as bituminous and anthracite, though some sub-bituminous and lignite coals in the western U.S. also produce Class F fly ash. Bituminous and anthracite coal fly ashes rarely contain more than 15% calcium oxide. Sub-bituminous fly ashes usually contain more than 20% calcium oxide and have both cementitious and pozzolanic properties. There are important performance differences between fly ashes from different sources. In general, sulfate-resistant characteristics and the ability of a fly ash to mitigate the effects of alkali-silica reaction in concrete are a function of the coal source. Strength enhancement characteristics of a fly ash vary widely, depending on the physical and chemical properties of the ash and the general characteristics of the cement in which it is used. Throughout this document, the terms Class F and Class C refer to fly ash characteristics defined in ASTM C 618.

1.2.1 *Production and processing*—The ash content of coals by mass may vary from 4 to 5% for sub-bituminous and anthracite coals, to as high as 35 to 40% for some lignites. The combustion process, which creates temperatures of approximately 1600 °C (2900 °F) liquefies the incombustible minerals. Rapid cooling of these liquefied minerals upon leaving the firebox causes them to form spherical particles with a predominantly glassy structure. Many variables can affect the characteristics of these particles. Among these are coal composition, grinding mill efficiency, the combustion environment (temperature and oxygen supply), boiler/burner configuration, and the rate of particle cooling.

Modern coal-fired power plants that burn coal from a uniform source generally produce very consistent fly ash. Fly ash particles, when from the same plant and coal source, will slightly vary in size, chemical composition, mineralogical

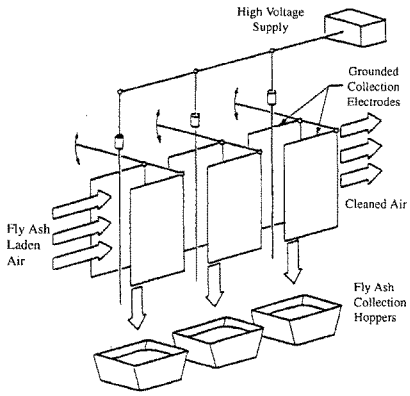

Fig. 1.1—Electrostatic precipitator.

composition, and density. Sizes may run from less than 1 μm (0.00004 in.) to more than 200 μm (0.008 in.), and density of individual particles from less than 1 Mg/m^3 (62.4 lb/ft^3) hollow spheres to more than 3 Mg/m^3 (187 lb/ft^3); although, the apparent true density of the bulk fly ash produced by a single coal-burning plant will typically not vary dramatically. Collection of these particles from the furnace exhaust gases is typically accomplished by electrostatic or mechanical precipitators or by bag houses. A typical gas flow pattern through an electrostatic precipitator is shown in Fig. 1.1.

As the fly ash particles are collected in a mechanical precipitator, they segregate in sequential precipitator hoppers according to their size and density; larger and heavier particles tend to accumulate closer to the fly-ash-laden air (gas inlet), while the smaller and lighter particles tend to collect farther from the inlet. In electrostatic precipitators, however, the particle size and density trends in sequential hoppers is disrupted due to the influence of the charged collection grids. The fineness, density, and carbon content of fly ash can vary significantly from hopper to hopper in both mechanical and electrostatic precipitators. The individual fly ash hoppers are usually emptied and conveyed to storage silos where fly ash is combined to produce a homogenous material.

1.2.2 *Impact of environmental regulations*—Nitrous oxide (NOx) emissions are considered to contribute to the production of acid rain in the U.S. The Clean Air Act required coal-fired boiler NOx emissions to be cut by 2 million tons from 1980 levels by 2000.

The use of NOx reduction technologies, such as low NOx combustion system burners (LNB) or overfire air (OFA), on electric power plants has, in some cases, had a negative impact on the utilization of the coal ash because of increased levels of unburned carbon and other chemical residuals that are left in the ash.

The combustion modifications that reduce the creation of NOx lower the peak flame temperature and reduce the excess oxygen present. These changes impact fly ash characteristics. Usually, the unburned carbon (UBC) level in the ash increases. Lower flame temperatures also produce less ash melting. As a consequence, the ash particle-size distribution can be coarsened and individual particle morphology can be less spherical.

It has also been suggested that the lower combustion temperatures modify the glass content and composition of fly ash. Changes in fly ash glass content and mineralization, combined with changes in particle-size distribution and particle morphology, can have a significant effect on fly ash reactivity. The magnitude of this effect can vary from significant to inconsequential, depending on the specific fuel and combustion modification system employed.

Post-combustion system technologies for reducing NOx emissions, such as selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR), also impact fly ash quality. Both of these systems involve introducing NH_3 into the flue gas stream by injecting agents such as ammonia or urea. The NH_3 is used to reduce NOx to harmless elemental nitrogen (N_2). Excess ammonia, however, may be available to deposit on the fly ash in the gas stream as ammonium salts such as ammonium bisulfate. These ammonium salts have been detected at concentrations ranging from barely measurable to levels in excess of several thousand mg/kg (Brendel, Rathbone, and Frey 2001). Low concentrations of ammonia have no impact on concrete properties (Koch and Dortmund 1989); however, a strong ammonia odor may be emitted. The ammonium salts will react to release ammonia gas if the ammoniated fly ash comes in contact with water under basic conditions such as exist in a concrete environment. The ammonia concentration, rate of evolution, and exposure level will depend on specific characteristics of the materials used and a large number of environmental factors. Some of the controlling factors are concentration of ammonia in the fly ash, concentration of fly ash in the concrete or controlled low-strength material (CLSM) mixture, mass of mixture, volume of space and degree of circulation enveloping a mixture, amount of mixing and transit time for a freshly mixed material, temperature, and wind speed (outdoor exposures).

Studies have reported on the release rate of ammonia gas from mortar systems during mixing (Rathbone, Tyra, and Harper 2002). A rapid method for determining the ammonia concentration of fly ash as a means for quality control of fly ash used for concrete was provided by Majors et al. (1999). When using fly ash containing ammonia, consideration should be given to material characteristics, applications, environment, and quality-control programs in place.

1.2.3 *Beneficiated fly ash*—Much fly ash produced from a power plant is suitable for use in concrete. If the quality of some or all of the fly ash produced is less than required by specification or market standards, however, methods may be used to beneficiate the fly ash. The properties that are commonly controlled by beneficiation are fineness and loss on ignition (LOI), an indicator of carbon content. The physical and chemical properties of fly ash can vary among individual precipitator or baghouse collection hoppers. This phenomenon

can be taken advantage of in some operations to produce a high-quality material. Where the control and piping systems in the power plant allow, fly ash can be selectively drawn from those hoppers that contain the higher-quality fly ash, while material of questionable quality is discarded.

Mechanical or air-classification equipment can be used to reduce the mean particle size of fly ash to meet specification or market requirements. Such classifiers effectively remove the denser particles and can be adjusted to vary the amount of coarser ash removed. Depending on the size, density, and distribution of particles containing carbon, the LOI can be increased, decreased, or unchanged by this technique. In general, the finer the fly ash, the lower the LOI and the greater the concrete's long-term compressive strength. Increased fineness also lowers the water demand and increases resistance to sulfate attack in concrete (EPRI ID-1006565). A typical centrifugal classifier installation involving one classifier, could beneficiate 54 to 91 Gg (60,000 to 100,000 tons) of classified material per year.

Numerous investigations have demonstrated that fly ash performance can be enhanced by significantly shifting the particle-size distribution to finer material (Butler 1981; Berry et al. 1989; Obla et al. 2001a). As compared to a normal fly ash with a mean particle diameter ranging from 15 to 35 μm (0.0006 to 0.0014 in.), processed fly ash can be produced with a mean particle diameter of 2.5 to 4.0 μm (0.0001 to 0.00016 in.). Particle-size reductions of this magnitude have been achieved by methods of specialized air classification systems (Cornelissan, Hellewaard, and Vissers 1995; Hassan and Cabrera 1998), and micronization (Paya et al. 1995; Bouzoubaâ et al. 1997). These processed, "ultra-fine fly ashes" can provide water reduction of 10 to 12% in mortar and reduce high-range water-reducer demand in concrete (Ferraris, Obla, and Hill 2001). Kruger, Sedat, and Dijkema (2001) and Obla et al. (2001a,b) have demonstrated that ultra-fine fly ashes contribute more toward concrete strength gain and permeability reduction than normal ASTM C 618 fly ash, and will, when properly proportioned, provide concrete characteristics comparable to highly reactive pozzolans such as silica fume. Concrete durability properties, such as resistance to alkali-silica reaction (Bérubé, Duchense, and Chouinard 1995), sulfate attack (Shashiprakash and Thomas 2001), and concrete permeability (Obla et al. 2000), are enhanced by ultra-fine fly ash. Technology is now available to reduce the carbon content of fly ashes. Triboelectric separation (Whitlock 1993) and carbon burnout techniques (Cochran and Boyd 1993) are commercially used to reduce the LOI of fly ash without deleterious effects to other properties. Triboelectric separation involves utilizing charge transfer between carbon and mineral particles occurring due to contact during conveying. The difference in charge separates the high carbon fraction from the carbon fraction of ash in a high-voltage electric field. Bittner and Gasiorowski (1999) reported on a commercial triboelectric process that uses a counter-current moving belt to facilitate the separation of carbon from fly ash in a high-voltage field. The report provides historical performance for a system that has been in operation since 1995. Triboelectric beneficiation systems have generated 450,000 Mg (500,000 tons) of ash per year. Triboelectric operations based on alternate designs have also been demonstrated but not commercialized (Li et al. 1999; Soong et al. 1999). Carbon burnout is another means for reducing fly ash carbon content. This process burns the residual carbon in fly ash as a fuel source in an auxiliary fluidized bed combustor, producing a pozzolan meeting the required carbon content. In the process, heat is recovered and returned to the power plant that originally produced the high-carbon ash. One commercially operating facility has reported processing capabilities of 162,000 Mg (180,000 tons) per year (EPRI ID1006565; Frady, Keppeler, and Knowles 1999). In addition to burning the carbon, the temperature of the combustor can remove ammonia from the ash (Giampa 2001).

Froth flotation is a method derived from mineral processing that separates carbon from fly ash by introducing the fly ash into a slurry system. The slurry contains frothing chemicals that facilitate the flotation of less-dense carbon particles; whereas the inorganic fraction of fly ash is sluiced to a collection area. The processed fly ash is dried before use (Groppo 2001). Froth flotation can be useful for removing very fine carbon (EPRI ID-1006565).

The potential for a fly ash to impact the air-entrainment level in concrete is not always a simple function of residual carbon mass—as indexed by LOI values. Early work sponsored by Hurt et al. (1995) suggested that carbon in fly ash is heterogeneous—ranging from coke-like to lacy in morphology. More recent studies point to the fact that fly ash from different sources can exhibit varying impact on air entrainment even though LOI values are almost equivalent (Hill et al. 1997; Hill, Hower, and Rathbone, 1998; Hill, Rathbone, and Majors 1999). Hill and others (Freeman et al. 1997; Gao et al. 1997) have highlighted the important role that total carbon surface area, available surface area, and surface reactivity play in the interaction between fly ash carbon and chemical air-entraining admixtures. Studies have shown the potential to affect the adsorptive properties of fly ash carbon by modifying carbon surface properties without significantly reducing the carbon mass (Sabanegh et al. 1997; Hill and Majors 2001). Hurt has suggested ozonation as a means for chemically passivating carbon against chemical interaction with air-entraining admixtures as a means for fly ash beneficiation (Hurt et al. 2000).

CHAPTER 2—FLY ASH COMPOSITION

2.1—General

Fly ash consists of heterogeneous combinations of amorphous (glassy) and crystalline phases. The largest fraction of fly ash consists of glassy spheres of two types: solid and hollow (cenospheres). These glassy spheres usually consist of 60 to 90% of the total mass of fly ash, with the remaining fraction of fly ash made up of a variety of crystalline phases. These two fractions are not completely independent of one another. Rather, the crystalline phases can be present within a glassy matrix or attached to the surface of the glassy spheres. This union of phases makes fly ash a complex material to classify and characterize in specific terms.

2.2—Chemical composition

The bulk chemical composition has been used by ASTM C 618 to classify fly ash into two types: Classes C and F. The chemical composition data used to determine compliance with ASTM C 618 do not address the nature or reactivity of the particles. This analysis is used as a quality-control or quality-assurance tool. Minor variations in the chemical composition of a particular fly ash do not relate directly to the long-term performance of concrete containing that fly ash. Although the constituents of fly ash are not normally present as oxides, the chemical composition of fly ash is so reported. The crystalline and glassy constituents that remain after the combustion of the pulverized coal are a result of materials with high melting points and incombustibility. The amounts of the four principal constituents—SiO_2 (35 to 60%), Al_2O_3 (10 to 30%), Fe_2O_3 (4 to 20%), and CaO (1 to 35%)—vary widely. The sum of the first three constituents (SiO_2, Al_2O_3, and Fe_2O_3) must exceed 70% to be classified as an ASTM C 618 Class F fly ash; whereas their sum must only exceed 50% to be classified as an ASTM C 618 Class C fly ash. Class C fly ashes generally contain more than 20% of material reported as CaO; therefore, the sum of the SiO_2, Al_2O_3, and Fe_2O_3 may be significantly less than the 70% Class F minimum limit.

The SiO_2 content of fly ash results mainly from the clay minerals and quartz in the coal. Anthracite and bituminous (higher ranked) coals often contain a higher percentage of clay minerals in their incombustible fraction than do sub-bituminous and lignite coals; therefore, the fly ash from the high-rank coals is richer in silica. The siliceous glass from the fly ash is the primary contributor to the pozzolanic reaction in concrete because it is the amorphous silica that combines with lime and water to form calcium silicate hydrate (C-S-H), the binder in concrete.

The principal source of alumina (Al_2O_3) in fly ash is the clay in the coal, with some alumina coming from the organic compounds in low-rank coal. The types of clays found in coal belong to three groups of clay minerals: smectite $[Na(Al_5Mg)Si_{12}O_{30}(OH)_6 \cdot nH_2O]$, illite $[KAl_5Si_7O_{20}(OH)_4]$, and kaolinite $[Al_4Si_4O_{10}(OH)_8]$.

Northern lignites typically contain a sodium smectite; whereas bituminous coal typically contains only members of the illite group and kaolinite. This difference in types of clay explains the lower Al_2O_3 in low-rank coal fly ash. From the alumina/silica ratios of smectite, 0.35; illite, 0.61; and kaolinite, 0.85, it is clear why lignite fly ashes usually contain 40% less analytic Al_2O_3 than bituminous fly ashes.

The Fe_2O_3 content of fly ash comes from the presence of iron-containing materials in the coal. The highest concentrations of iron-rich fly ash particles are between 30 and 60 μm (0.0012 and 0.0024 in.), with the lowest iron contents in particles less than 15 μm (0.0006 in.).

The source of the materials reported as CaO in fly ash is calcium, primarily from calcium carbonates and calcium sulfates in the coal. High-rank coals, such as anthracite and bituminous coal, contain smaller amounts of noncombustible materials, usually showing less than 5% CaO in the ash. Low-rank coals can produce fly ash with up to 35% CaO. The southern lignite coals found in Texas and Louisiana show the least CaO of the low-rank coals, at about 10%.

Calcium oxide concentration has been suggested as another means of classifying coal fly ash. Thomas, Shehata, and Shashiprakash (1999) describe and discuss a recent revision of CSA A3000 to distinguish between fly ashes that have different effects on properties of fresh and hardened concrete, principally the total calcium content, expressed as percent by mass as CaO, as follows:

Type	CaO, %	Loss on ignition, %
F	< 8	8 max.
CI	8 to 20	6 max.
CH	> 20	6 max.

They concluded that calcium oxide could be used as a reasonable measure of the general chemical composition of fly ash and its influence on concrete properties.

The MgO in fly ash is derived from organic constituents, smectite, ferromagnesian minerals, and sometimes dolomite. These constituents are usually minimal in high-rank coals, but can result in MgO contents exceeding 7% in fly ashes from sub-bituminous and northern lignites (lignite coal sources in North Dakota, Saskatchewan, and surrounding areas). Southern lignites (from Texas and Louisiana) have MgO contents of less than 2%.

The SO_3 in fly ash is a result of pyrite (FeS_2) and gypsum ($CaSO_4 \cdot 2H_2O$) in the coal. The sulfur is released as sulfur dioxide gas and precipitated onto the fly ash or "scrubbed" from the flue gases, through a reaction with lime and alkali particles.

The alkalis in fly ash come from the clay minerals and other sodium and potassium-containing constituents in the coal. Alkali sulfates in northern lignite fly ash result from the combination of sodium and potassium with oxidized pyrite, organic sulfur, and gypsum in the coal. McCarthy et al. (1988) reported that Na_2O is found in greater amounts than K_2O in lignite and sub-bituminous fly ash, but the reverse is true of bituminous fly ash. Expressed as Na_2O equivalent (percent Na_2O + 0.658 × percent K_2O) alkali contents are typically less than 5%, but may be as high as 10% in some high-calcium fly ashes.

The carbon content in fly ash is a result of incomplete combustion of the coal and organic additives used in the collection process. Carbon content is not usually determined directly, but is often assumed to be approximately equal to the LOI; however, LOI will also include any combined water or CO_2 lost by decomposition of hydrates or carbonates that are present in the ash. The analytical carbon concentration of most fly ashes will correlate well with LOI values, but the actual carbon content will usually range from 0.3 to 0.8% less than the LOI value. Class C fly ashes usually have LOI values less than 1%, but Class F fly ashes range from this low level to values as high as 20%. Fly ashes used in concrete typically have less than 6% LOI; however, ASTM C 618 provides for the use of Class F fly ash with up to 12.0% LOI if either acceptable performance records or laboratory test results are made available.

Minor elements that may be present in fly ash include varying amounts of titanium, phosphorus, lead, chromium,

and strontium. Some fly ashes also have trace amounts of organic compounds other than unburned coal. These additional compounds are usually from stack additives and are discussed in a subsequent section.

Table 2.1 gives typical values of North American fly ash bulk chemical composition for different sources. Other references that provide detailed chemical composition data are also available (Berry and Hemmings 1983; McCarthy et al. 1984; Tikalsky, Carrasquillo, and Snow 1992).

2.3—Crystalline constituents

From the bulk chemical composition of fly ash, a division can be made between the phases in which these chemical compounds exist in fly ash. Developments in the techniques of quantitative x-ray diffraction (XRD) analysis have made it possible to determine the approximate amounts of crystalline phases in fly ash (Mings et al. 1983; Pitt and Demirel 1983; McCarthy et al. 1988).

Low-calcium fly ashes contain only relatively chemically inactive crystalline phases: quartz, mullite, ferrite spinel, and hematite (Diamond and Lopez-Flores 1981). High-calcium fly ash can contain the previously mentioned phases, and may also contain additional crystalline phases such as: anhydrite, alkali sulfate, dicalcium silicate, tricalcium aluminate, lime, melilite, merwinite, periclase, and sodalite (McCarthy et al. 1984). The additional phases found in Class C fly ash are reactive, and this explains why Class C fly ash exhibits both cementitious and pozzolanic properties. A list of crystalline compounds found in fly ash is given in Table 2.2.

Alpha quartz is present in all fly ash. The quartz is a result of the impurities in the coal that failed to melt during combustion. Quartz is typically the most intense peak in the XRD pattern, but this peak is also subject to the most quantitative variability.

Mullite is found in substantial quantities only in low-calcium fly ashes. Mullite forms within the glass spheres as they solidify around it. It is the largest source of alumina in fly ash and is not normally chemically reactive in concrete.

In its purest form, magnetite (Fe_3O_4) is the crystalline spinel structure closest to that found in fly ash. A slight decrease in the diffraction spacing of ferrite spinel is detected through XRD. Stevenson and Huber (1987) used a scanning electron microscope (SEM) electron probe on a magnetically separated portion of the fly ash to determine that the cause of this deviation is the Mg and Al substitution in the structure of this phase as an iron replacement. The ferrite spinel phase found in fly ash is not chemically active. Hematite (Fe_2O_3), formed by the oxidation of magnetite, is also present in some fly ashes; it too is not chemically active.

Coal ashes containing high calcium contents often contain between 1 and 3% anhydrite ($CaSO_4$). The calcium acts as a "scrubber" for SO_2 in the combustion gases and forms anhydrite. Crystalline CaO ("free lime") is present in most high-calcium fly ashes and may be a cause of autoclave expansion. Lime in the form of $Ca(OH)_2$ ("slaked lime"), however, does not contribute to autoclave expansion. Soft-burned CaO hydrates quickly and does not result in unsoundness in concrete; however, hard-burned CaO formed at higher temperatures hydrates slowly after the concrete has hardened. Demirel et al. (1983) hypothesize that the carbon-dioxide-rich environment of the combustion gases causes a carbonate coating to form on poorly burned CaO particles, creating a high-diffusion energy barrier. This barrier retards the hydration of the particle and thereby increases the potential for unsoundness. If free lime is present as highly sintered, hard-burned material, there is a potential for long-term deleterious expansion from its hydration. Although there is no direct way to separate soft-burned lime from the sintered lime, McCarthy et al. (1984) note that when hard-burned lime is present, it is often found in the larger grains of fly ash. If there is sufficient hard-burned CaO to cause unsoundness, it can be detected as excessive autoclave expansion. Class F fly ash samples that were tested at the source by the Corps of Engineers at the Waterways Experiment Station and resampled by the North Pacific Division Laboratory at the site had extreme autoclave expansion. XRD showed CaO but not

Table 2.1—Example bulk composition of fly ash with coal sources

	Bituminous	Sub-bituminous	Northern lignite	Southern lignite
SiO_2, %	45.9	31.3	44.6	52.9
Al_2O_3, %	24.2	22.5	15.5	17.9
Fe_2O_3, %	4.7	5.0	7.7	9.0
CaO, %	3.7	28.0	20.9	9.6
SO_3,%	0.4	2.3	1.5	0.9
MgO, %	0.0	4.3	6.1	1.7
Alkalies, %*	0.2	1.6	0.9	0.6
Loss on ignition, %	3	0.3	0.4	0.4
Air permeability fineness, m^2/kg	403	393	329	256
45 μm sieve retention, %	18.2	17.0	21.6	23.8
Density, Mg/m^3	2.28	2.70	2.54	2.43

*Available alkalies expressed as Na_2O equivalent.

Table 2.2—Mineralogical phases in fly ash

Mineral name	Chemical composition
Thenardite	$(Na,K)_2SO_4$
Anhydrite	$CaSO_4$
Tricalcium aluminate (C_3A)	$Ca_3Al_2O_6$
Dicalcium silicate (C_2S)	Ca_2SiO_4
Hematite	Fe_2O_3
Lime	CaO
Melilite	$Ca_2(Mg,Al)(Al,Si)_2O_7$
Merwinite	$Ca_3Mg(SiO_2)_2$
Mullite	$Al_6Si_2O_3$
Periclase	MgO
Quartz	SiO_2
Sodalite structures	$Na_8Al_8Si_6O_{24}SO_4$ $Na_6Ca_2Al_6Si_6O_{24}(SO_4)_2$ $Ca_8Al_{12}O_{24}(SO_4)_2$
Ferrite spinel	Fe_3O_4
Portlandite	$Ca(OH)_2$

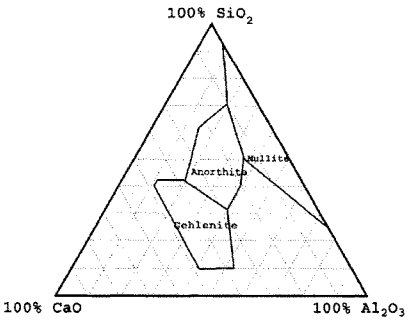

Fig. 2.1—CaO-SiO_2-Al_2O_3 ternary system diagram.

MgO. After leaving the autoclave bars in moist curing another day and expecting that expansion would be reduced, it doubled. Examination revealed that CaO was in the largest particles, and several were apparently glass coated. Cores showed no abnormalities so the original acceptance was not invalidated. $Ca(OH)_2$ is also present in some high-calcium fly ash that have been exposed to moisture.

Crystalline MgO (periclase) is found in fly ashes with more than 2% MgO. Fly ash from low-rank coals can contain periclase contents as high as 80% of the MgO content. The periclase in fly ash is not "free" MgO like that found in some portland cements. Rather, the crystalline MgO in fly ash is similar to the phase of MgO found in granulated blast-furnace slags in that it is nonreactive in water or basic solutions at normal temperatures (Locher 1960).

Phases belonging to the melilite group include:

Gehlenite ($Ca_3Al_2Si_2O_{10}$); and
Akermanite ($Ca_4Si_3O_{10}$).

These phases have been detected in fly ash but are not chemically active in concrete. Each of these phases can have an Fe substituted for Mg or Al. Merwinite is a common phase in high-calcium fly ash, and the early stages of the devitrification of Mg-containing glasses. Northern lignites typically have higher MgO contents and lower Al_2O_3 contents than subbituminous-coal fly ash, allowing the merwinite phase to dominate over the C_3A phase in the northern lignite fly ash. Merwinite is nonreactive at normal temperatures.

The presence of C_3A in high-calcium fly ash was confirmed by Diamond (1981) and others. The intense XRD peaks of this phase overlap those of the merwinite phase, making the quantitative interpretation difficult. McCarthy et al. (1988), however, reported that the C_3A phase is the dominant phase in fly ash with subbituminous-coal sources, and the merwinite phase is dominant in lignite fly ashes. Neither phase is present in low-calcium fly ash. The cementitious value of C_3A contributes to the self-cementing property of high-calcium fly ashes. The C_3A phase is extremely reactive in the presence of calcium and sulfate ions in solution.

Phases belonging to the sodalite group, formed from melts rich in alkalies, sulfate, and calcium, have a low silica content. Nosean and hauyne phases have been identified in fly ash by McCarthy et al. (1988). Some researchers have found tetracalcium trialuminate sulfate ($C_4A_3\bar{S}$) in Class C ash, the active constituent of Type K expansive cement. $C_4A_3\bar{S}$ reacts readily with water, lime, and sulfate to form ettringite.

Among the other phases found in fly ash are alkali sulfate and dicalcium silicate. Dicalcium silicate (C_2S) is a crystalline phase that is present in some high-calcium fly ashes. Northern lignite fly ash often contain crystalline alkali sulfates such as thenardite and aphthitilite.

Tishmack, Olek, and Diamond (1999) investigated high-calcium Class C fly ashes derived from Powder River Basin coal, which contains significant amounts of sulfur, calcium, and aluminum, and thus is a potential source of ettringite in concrete. Hydration products of fly-ash water pastes contain ettringite ($C_6A\bar{S}_3H_{32}$), monosulfate ($C_4A\bar{S}H_{12}$), and stratlingite (C_2ASH_8). Portland cement/fly ash pastes were found to contain calcium hydroxide, ettringite, monosulfate, and smaller amounts of hemicarboaluminate and monocarboaluminate. The cement/fly ash pastes generally formed less ettringite than did the control cement pastes but formed more of the monosulfate phases.

2.4—Glassy constituents

Fly ash consists largely of small glassy spheres that form while the burned coal residue cools very rapidly. The composition of these glasses is dependent on the composition of the pulverized coal and the temperature at which it is burned. Fly ash glass content and glass composition strongly determines its reactivity. The major differences in fly ash glass composition lie in the amount of calcium present in the glass. Coal that has only small amounts of calcium—for example, anthracite and bituminous or some lignite coals—result in aluminosilicate glassy fly ash particles. Sub-bituminous and some lignite coals leave larger amounts of calcium in the fly ash and result in calcium aluminosilicate glassy phases (Roy, Luke, and Diamond 1984). This can be seen in the ternary system diagram shown in Fig. 2.1. The normalized average glass composition of high-calcium fly ash falls within the ranges where anorthite to gehlenite are the first phases to crystallize from a melt, whereas the low-calcium fly ashes fall within the regions of the diagram where mullite is the primary crystalline phase. The disordered structure of a glass resembles that of the primary crystallization phase that forms on cooling from the melt. In fly ash, the molten silica is accompanied by other molten oxides. As the melt is quenched, these additional oxides create added disorder in the silica glass network. The greater the disorder and depolymerization of the fly-ash glass structure, the less stable the network becomes.

In a simplified model, the mass of crystalline compounds is subtracted from the bulk mass, which yields the mass of the glassy portion of the fly ash. Extending this model to chemical compounds, the crystalline composition can be stoichiometrically subtracted from the bulk chemical composition to yield an average composition of the glass for any given fly ash. This is of importance when considering the level of reactivity of a fly ash.

The ternary diagram shown in Fig. 2.1 can also be used to illustrate the basic composition of the glassy portion of fly

ash. Fly ashes that have calcium-rich glassy phases are considerably more reactive than aluminosilicate glasses. Glasses in fly ash with a devitrified composition furthest from the mullite fields are most reactive within a hydraulic cement fly ash system because they have the most disordered network. This would indicate that fly ash containing high-calcium or high-alkali glasses possess a greater reactivity at early ages than low-calcium or low-alkali fly ashes, although this should be evaluated on a case-by-case basis. Additional discussions on the glass phases existing in fly ash can be found in Hemmings and Barry (1988) and Pietersen (1993).

2.5—Physical properties

The shape, size, particle-size distribution, and density of fly ash particles influence the properties of freshly mixed, unhardened concrete, and the strength development and other properties of hardened concrete. This is due in part to the influence of particle characteristics on the water demand of the concrete mixture. The properties of a fly ash produced at a particular power plant can vary from another fly ash originating from a different source. This is likely to be the case if the power plants are burning different coals or operate using different combustion systems. Plants operating under similar combustion regimes can produce fly ash with very similar chemical and physical characteristics. In addition, fly ashes produced at different power plants or at one plant with different coal sources may have different colors.

Fly ash color and the amount used can influence the color of the resulting hardened concrete in the same way as changes in cement or fine aggregate color. Fly ash color is generally not an engineering concern unless aesthetic considerations relating to the concrete require maintaining a uniform color in exposed concrete. A change in the color of an ash from a particular source can indicate changes in coal source, carbon content, iron content, or burning conditions and, therefore, changed properties.

2.5.1 *Particle shape*—Particle size and shape characteristics of fly ash are dependent on the source and uniformity of the coal, the degree of pulverization before burning, the combustion environment (temperature level and oxygen supply), uniformity of combustion, and the type of collection system used (mechanical separators, baghouse filters, or electrostatic precipitators). Lane and Best (1982) reported that the shape of fly ash particles is also a function of particle size. The majority of fly ash particles are glassy, solid, or hollow, and spherical in shape. Examples of fly ash particle shapes are shown in Fig. 2.2 and 2.3. Fly ash particles that are hollow are translucent to opaque, slightly to highly porous, and vary in shape from rounded to elongated. The intergrinding of fly ash with portland-cement clinker in the production of blended cement has improved its contribution to strength (EPRI SC-2616-SR). Grinding further reduces particle size, breaks up cenospheres, and separates particles that have surface attractions. As the mixture of fly ash and cement clinker is ground, an optimum fineness for water requirements can be established.

2.5.2 *Fineness*—Individual particles in fly ash range in size from less than 1 μm (0.00004 in.) to greater than 1 mm

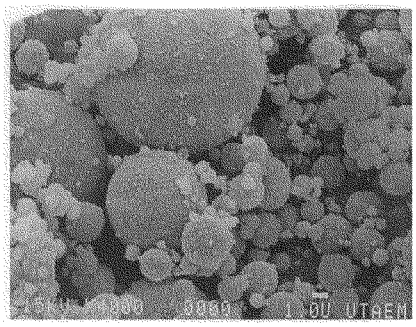

Fig 2.2—Fly ash at 4000× magnification.

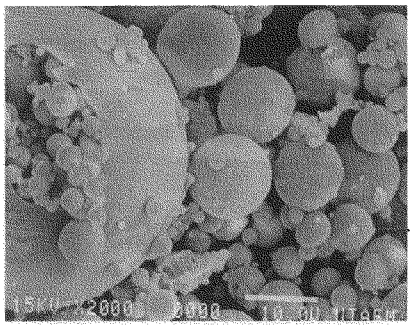

Fig 2.3—Fly ash showing plerospheres at 2000× magnification.

(0.04 in.). A coarse fly ash often contains more porous particles with openings—pleroshperes (Fig. 2.3). Fly ash of 5 to 30 micron particle size is highly reactive compared to coarser fly ash (Malhotra and Mehta 2002). In older plants where mechanical separators are used, the fly ash is coarser than in more modern plants that use electrostatic precipitators or bag filters. Fly ash that is suitable for use in concrete (ASTM C 618) shall have not more than 34% of the particles retained on the 45 μm (No. 325 [0.0018 in.]) sieve. The 45 μm (No. 325 [0.0018 in.]) sieve analysis of fly ash from a particular source will normally remain relatively constant, provided there are no major changes in the coal source, coal grinding, process operations, and plant load. Minor variations can be expected due to sampling techniques.

Fineness of a specific fly ash may have an influence on its performance in concrete. Lane and Best (1982) used ASTM C 430 45 μm (No. 325 [0.0018 in.]) sieve fineness tests results as a means to correlate the fineness of Class F fly ash with certain concrete properties. For a particular source of fly ash, their data indicate that concrete strength, abrasion resistance, and resistance to freezing and thawing are direct

functions of the proportion of the fly ash finer than the 45 μm (No. 325 [0.0018 in.]) sieve. They concluded that fineness within a particular source is a relatively consistent indicator of fly ash performance in concrete and that performance improves with increased fineness.

Fly ash fineness test methods (other than the ASTM C 430) are the air-permeability test (ASTM C 204), the turbidimeter method (ASTM C 115), and the hydrometer method. Fineness values obtained from these three tests can differ widely, depending on the procedure used. The test results are also strongly influenced by the density and porosity of the individual particles. The air-permeability test procedure provides a rapid method for detecting changes. Increased surface area, as determined by air-permeability tests, correlates with higher reactivity, especially when comparing ashes from a single source. Exceptions to this trend are found with some high-carbon fly ashes, which tend to have high fineness values that may be misleading. Useful information on size distribution of particles finer than 45 μm (No. 325 [0.0018 in.]) sieve can be obtained by sonic sifting and by particle sizing equipment based on laser scattering (Popovics 1993). Data on the particle-size distribution of several Class C and F fly ashes indicate that a large percentage of particles smaller than 10 μm (0.0004 in.) had a positive influence on strength (EPRI CS-3314).

2.5.3 *Density*—According to Luke (1961), the density of solid fly ash particles ranges from 1.97 to 3.02 Mg/m^3 (123 to 188 lb/ft^3), but is normally in the range of 2.2 to 2.8 Mg/m^3 (137 to 175 lb/ft^3). Some fly ash particles, such as cenospheres, are capable of floating on water. High density is often an indication of fine particles. Roy, Luke, and Diamond (1984) indicate that fly ashes high in iron tend to have higher densities, and those high in carbon have lower densities. ASTM Class C fly ashes tend to have finer particles and fewer cenospheres; thus, their densities tend to be higher, in the range of 2.4 to 2.8 Mg/m^3 (150 to 175 lb/ft^3).

2.5.4 *Trace metals in fly ash*—Coal fly ash particles, much like volcanic ash, are essentially insoluble aluminosilicate glasses. Ash consists of limestone, iron, aluminum, silica sand, and clay—essentially materials from the earth's crust oxidized by the heat of combustion.

In addition, coal ash contains trace quantities (in the parts-per-million range) of the oxidized forms of other naturally occurring elements. These same elements exist in soil, rock, and coal. Such trace elements typically include arsenic, boron, cadmium, chromium, copper, lead, selenium, and zinc, which can have adverse effects on human health if inhaled or ingested in sufficient quantity. Coal ash composition and mineralogy (including its trace element content and form) varies among power plants and is primarily related to that of the source coal and combustion conditions.

The U.S. Environmental Protection Agency (EPA) has reviewed extensive studies on coal ash for health and environmental risks and has examined coal ash samples collected from power plants around the country. In 1999, the agency determined that power-plant coal ash is nonhazardous and should be regulated accordingly. This determination culminated a 19-year review in accordance with the 1980 Resource Conservation and Recovery Act's Bevill Amendment, which directed the EPA to review the issue and prepare a report to Congress.

2.6—Chemical activity of fly ash in hydraulic cement concrete

The principal products of the reactions of fly ash with calcium hydroxide and alkali in concrete is the same as that of the hydration of portland cement, calcium silicate hydrates (C-S-H), and calcium aluminate hydrates. The morphology of the Class F fly ash reaction product is suggested to be more gel-like and denser than that from portland cement (Idorn 1983). The reaction of fly ash depends largely on breakdown and dissolution of the glassy structure by the hydroxide ions and the heat generated during the early hydration of the hydraulic cement fraction. The reaction of the fly ash continues to consume $CaOH_2$ to form additional C-S-H, as long as $CaOH_2$ is present in the pore fluid of the cement paste and as long as there is remaining mixing water filling space that the C-S-H can occupy; at $w/cm < 0.4$ by mass, there will be more space available before all cementitious material react (Philleo 1991). Regourd (1983) indicated that a very small, immediate chemical reaction also takes place when fly ash is mixed with water, preferentially releasing calcium and aluminum ions to solution. This reaction is limited, however, until additional alkali or calcium hydroxide or sulfates are available for reaction. The amount of heat evolved as a consequence of the reactions in concrete is usually reduced when fly ash is proportioned together with portland cement in the concrete. The rate of early heat evolution is reduced in these cases and the time of maximum rate of heat evolution is retarded (Mehta 1983; Wei, Grutzeck, and Roy 1984). When the quantity of portland cement per unit volume of concrete is kept constant, the heat evolved is increased by fly ash addition (Mehta 1983). Ma et al. (1994) ran an extensive calorimetric study of portland and blended cements systems containing a Class F fly ash to determine their activation energies. They reported that hydration is controlled by the same mechanism for all the blended cement systems tested.

Idorn (1984) has suggested that, in general, fly-ash reaction with portland cement in modern concrete is a two-stage reaction. Initially and during the early curing, the primary reaction is with alkali hydroxides and, subsequently, the main reaction is with $CaOH_2$. This distinction is not apparent when research is conducted at room temperature; at room temperature, the slower $CaOH_2$ activation prevails and the early alkali activation is minimized. As was shown to be the case for portland cement by Verbeck (1960), the pozzolanic reaction of fly ashes with lime and water follows Arrhenius' law for the interdependence of temperatures and the rates of reaction. An increase in temperature causes a more-than-proportionate increase in the reaction rate.

Clarifying the basic principles of fly ash reaction makes it possible to identify the primary factors that, in practice, will influence the effectiveness of the use of fly ash in concrete. These factors include:

(a) The chemical and phase composition of the fly ash and of the hydraulic cement;

(b) The alkali-hydroxide concentration of the reaction system;

(c) The morphology of the fly ash particles;

(d) The fineness of the fly ash and of the hydraulic cement;

(e) The development of heat during the early phases of the hydration process; and

(f) The reduction in mixing water requirements when using fly ash.

Variations in chemical composition and reactivity of fly ash affect early stage properties and the rheology of concrete (Roy, Skalny, and Diamond 1982).

It is difficult to predict concrete performance through characterization of fly ashes by themselves. Fly ash acceptability with regard to workability, strength characteristics, and durability should be investigated through trial mixtures of concrete containing the fly ash.

2.7—Future research needs

Future research needs in the area of fly ash composition include:

(a) A better understanding of the effects of particle-size distribution;

(b) Clarification of the influence of carbon particles as a function of their size and adsorption capability for chemical admixtures;

(c) A better understanding of the nature of constituents in fly ash containing higher CaO concentration and how these fly ashes can affect the performance of concrete in the fresh and hardened states;

(d) A better understanding of the effects that fly ash has on concrete microstructure and porosity over time and how these effects can be quantitatively related to concrete service life through the use of chloride diffusion data and service life models;

(e) A better characterization of the glass phases in fly ash and their effect on pozzolanic properties; and

(f) A better understanding of the effects that fly ash have on concrete performance after the concrete has been exposed to deicer salts.

CHAPTER 3—EFFECTS OF FLY ASH ON CONCRETE

3.1—Effects on properties of fresh concrete

3.1.1 *Workability*—Fly ash typically has a lower specific gravity than cement. Therefore, when fly ash is used to replace a portion of cement in a unit volume of concrete, the amount of paste (assuming the *w/cm* is constant) will increase. In many cases, fly ash may be used as an addition or as a replacement and addition material (replacement ratio of greater than 1). This will result in a greater increase in paste volume for a given water content. Usually, this increase in paste volume produces a concrete with greater plasticity and better cohesiveness (Lane 1983). In addition, the increase in the volume of fines from fly ash can compensate for deficient aggregate fines. Fly ash changes the flow behavior of the cement paste (Rudzinski 1984). The generally spherical shape of fly ash particles normally permits the water in the concrete to be reduced for a given workability (Brown 1980). Ravina (1984) reported on a Class F fly ash that reduced the rate of slump loss compared to non-fly ash concrete in hot weather conditions. Class C fly ashes generally have a high proportion of particles finer than 10 μm (0.0004 in.) (EPRI CS-3314), which favorably influences concrete workability. Data on the rheology of fresh fly ash cement-water mixtures were reviewed in detail by Helmuth (1987).

3.1.2 *Bleeding*—Using fly ash in air-entrained and non-air-entrained concrete mixtures usually reduces bleeding by providing a greater surface area of solid particles and requiring a lower water content for a given workability (Idorn and Henriksen 1984).

3.1.3 *Pumpability*—Improved pumpability of concrete usually results when fly ash is used. For mixtures deficient in the smaller sizes of fine aggregate or of low cement content, the addition of fly ash will make concrete or mortar more cohesive and less prone to segregation and bleeding. Further, the spherical shape of the fly ash particles serves to increase workability and pumpability by decreasing friction between particles and between the concrete and the pump line (Best and Lane 1980).

3.1.4 *Time of setting*—The use of fly ash can extend the time of setting of concrete if the hydraulic cement content is reduced. Jawed and Skalny (1981) found that Class F fly ashes retarded early C_3S hydration. Grutzeck, Wei, and Roy (1984) and Eren, Brooks, and Celik (1995) also found retardation with Class C fly ash. The setting characteristics of concrete are influenced by ambient temperature and concrete temperature; cement type, source, content, and fineness; water content; water-soluble alkalies; use and dosages of several types of chemical admixtures; the amount of fly ash; and the fineness and chemical composition of the fly ash (Plowman and Cabrera 1984). When these factors are given proper consideration in the concrete mixture proportioning, an acceptable time of set can be obtained. The actual effect of a given fly ash on time of setting can be determined by testing when a precise determination is needed or by observation when a less precise determination is acceptable. Pressures on formwork can be increased when fly ash concrete is used if increased workability, slower slump loss, or extended-setting characteristics are encountered (Gardner 1984).

3.1.5 *Finishability*—Where Class F fly ash is used as an addition to cement content, time of setting is usually not impacted. Replacement of cement with Class F fly ash will often provide retardation in accordance with the amount of cement removed from the mixture. The cementitious properties of Class C fly ash can influence cement hydration to a greater extent than Class F, thus leading to more retardation in some cases and less in others. When fly ash concrete has a longer time of setting than concrete without fly ash, finishing should be delayed (just as with a slow-setting concrete without fly ash). Failure to finish slower-setting concrete at a later time could lead to premature finishing, which can seal the bleed water under the top surface, creating a plane of weakness. Set times can often be managed through the use of chemical admixtures and proportioning. Tests should be conducted to determine how a specific group of materials

interact. Longer set times for concrete with or without fly ash can increase the probability of plastic shrinkage cracking or surface crusting under conditions of high evaporation rates. Using very wet mixtures containing fly ashes with significant amounts of very light unburned coal particles or cenospheres can cause these particles to migrate upward and collect at the surface, which can lead to an unacceptable appearance. Sometimes the addition of fly ash results in stickiness and consequent difficulties in finishing. In such cases, the concrete may have too much fine material or too high of an air content.

3.1.6 *Air entrainment*—The use of fly ash in air-entrained concrete will generally require a change in the dosage of the air-entraining admixture. Some fly ashes, however, require little or no increase in the air-entraining admixture dosage. In fact, some Class C fly ashes can reduce the amount of air-entraining admixture required, particularly for those with significant water-soluble alkalies in the fly ash (Pistilli 1983). When using a fly ash with a high LOI, more frequent testing of air content at the point of placement is desirable to maintain control of air content in the concrete.

Meininger (1981) and Gebler and Klieger (1983) have shown that those fly ashes that require a higher admixture dosage (with similar *w/cm* to mixtures not containing fly ash) tend to exhibit more air loss in fresh concrete. When this problem is suspected, air tests should be made as the concrete is placed to measure the magnitude of the loss in air content and to provide information necessary to adjust the dosage level for adequate air content at the time of placement. Meininger (1981) showed that once the mixture is placed in the forms, no further appreciable loss of air content is encountered. Agitation of the concrete is a prerequisite for loss of air content to continue.

In one investigation dealing with air entrainment (Gebler and Klieger 1983), the retention of air content over a 90 min period in different fly ash concrete ranged from about 40 to 100%, as measured on the fresh concrete, expressed on the basis of the initial air content. Air contents were also measured in the hardened concrete. This particular study showed that for conditions where the air reduction occurred, the air content in the hardened concrete was not reduced below 3.5%. The spacing factor increased somewhat, but not above the accepted limit of 0.20 mm (0.008 in.).

The loss of air depends on a number of factors: properties and proportions of fly ash; cement; fine aggregate; length of mixing or agitating time; and type of air-entraining admixture used (Gaynor 1980; Meininger 1981).

The foam-index test (Section 5.8) is a rapid quality-control test that can be used to check successive shipments of fly ash to detect a change in the required dosage of air-entraining admixture in concrete. The test is used to predict needed adjustments in the admixture dosage. When the foam-index value increases by a large amount, the potential loss of air during delivery and placement should be checked. For quality-control purposes, a procedure can be adapted from Meininger (1981) or Gebler and Klieger (1983) that, when used in a consistent manner, can be useful at ready-mixed concrete plants.

3.2—Effects on properties of hardened concrete

3.2.1 *Compressive strength and rate of strength gain*—Both the strength at a given age and the rate of strength gain of fly ash concrete are affected by the characteristics of the particular fly ash, the cement with which it is used, and the proportions of each used in the concrete (EPRI CS-3314). Compared with concrete without fly ash proportioned for equivalent 28-day compressive strength, concrete containing a Class F fly ash can develop lower strength at 7 days or less when tested at room temperature (Abdun-Nur 1961). By using accelerators, activators, water reducers, or by changing the mixture proportions, equivalent 3- or 7-day strength may be achieved (Bhardwaj, Batra, and Sastry 1980; Swamy, Ali, and Theodorakopoulos 1983; Dhir, Zhu, and McCarthy 1998; Shi and Qian 2000). For example, test results indicate that silica fume can be used in concrete containing fly ash to increase the early strength. Simultaneous use of silica fume and fly ash resulted in a continuing increase in 56- and 91- day strengths, indicating the presence of sufficient calcium ions for both the silica fume reaction and the longer-term fly ash reaction to continue (Carette and Malhotra 1983). Also, Mukherjee, Loughborough, and Malhotra (1982) have shown that increased early strengths can be achieved in fly ash concrete by using high-range water-reducing admixtures and reducing the *w/cm* to at least as low as 0.28.

After the rate of strength gain of hydraulic cement slows, the continued pozzolanic activity of fly ash provides strength gain at later ages if the concrete is kept moist; therefore, concrete containing fly ash with equivalent or lower strength at early ages may have equivalent or higher strength at later ages than concrete without fly ash. This strength gain will continue with time and result in higher later-age strengths than can be achieved by using additional cement (Berry and Malhotra 1980). Using 28-day strengths as references, Lane and Best (1982) reported strength increases of 50% at 1 year for concrete containing fly ash, as compared with 30% for concrete without fly ash. Other tests, comparing concrete with and without fly ash, showed significantly higher performance for the concrete containing fly ash at ages up to 10 years (Mather 1965). The ability of fly ash to aid in achieving high ultimate strengths has made it a very useful ingredient in the production of high-strength concrete (Blick, Peterson, and Winter 1974; Schmidt and Hoffman 1975; Joshi 1979).

Class C fly ashes often exhibit a higher rate of reaction at early ages than Class F fly ashes (Smith, Raba, and Mearing 1982). Even though Class C fly ash displays increased early-age activity, strength at later ages in high-strength concrete appears to be quite acceptable. Class C fly ashes typically give very good strength results at 28 days. Cook (1981) and Pitt and Demirel (1983) reported that some Class C fly ashes were as effective as hydraulic cement on an equivalent-mass basis. Certain Class C fly ashes, however, may not show the later-age strength gain typical of Class F fly ashes. The effect of an Australian Class F fly ash on strength development with different cements was demonstrated by Samarin, Munn, and Ashby (1983) and is shown in Fig. 3.1. Strength development for a Class C fly ash is shown in Fig. 3.2.

Elevated temperature curing has a much more beneficial effect on the early strength and strength gain of concrete containing fly ash than on concrete without fly ash. It can be explained by the apparent higher activation energy for pozzolanic reactions than that for hydration of cement. Large quantities of coarse fly ash may be used effectively in concrete under thermal curing conditions, with a significant improvement in its compressive strength, in contrast to the rather limited contribution under normal curing conditions at ages up to 28 days (Ravina 1981).

Cook (1982), with Class C fly ash, and Brink and Halstead (1956), with Class F fly ash, showed that, in most cases, the pozzolanic activity increased at all ages proportionally with the percent passing the 45 μm (No. 325 [0.0018 in.]) sieve. Both Brink and Halstead (1956) and Mather (1958) showed that changes in the cement source can change the strengths of concrete with Class F fly ash as much as 20%. For example, cements with alkali contents of 0.60% Na_2O equivalent or more usually perform better with fly ash for strength measured beyond 28 days.

Popovics (1986), after analyzing Ghosh's (1976) test results and from his own experiments, noticed that the strength differences between plain portland-cement concrete and fly ash concrete decreased with the decrease of *w/cm*. He found that just like plain portland cement concrete, fly ash concrete follows Abram's (Abram 1919) rule not only qualitatively, but also quantitatively, that is, the strength F can be approximated as follows:

$$F = A/B^{[w/(c+p)]}$$

where $w/(c+p)$ is the *w/cm*, and A and B are the appropriate parameters. Using Abram's rule, Popovics (1991) predicted strength contributions from the fly ash and cement phases in a fly ash concrete. His experiments indicated that even at 1 day, concrete containing 25% Class F fly ash had higher strengths than the predicted strength contribution from the cement phase alone. If the Class F fly ash did not react chemically with other components, where did the strength increase come from? Popovics suggested that this strength increase could be either attributed to the reduction in initial porosity of the paste by fine particles of fly ash and quartz powder or to the acceleration of hydration of the cement phase due to nucleation effects from fly ash particles for calcium silicate hydrate (C-S-H) gel.

3.2.2 *Modulus of elasticity*—Lane and Best (1982) report that the modulus of elasticity of Class F fly ash concrete and its compressive strength is somewhat lower at early ages and a little higher at later ages than similar concrete without fly ash. The effects of fly ash on modulus of elasticity are not as significant as the effects of fly ash on compressive strength. Figure 3.3 shows a comparative stress-strain relationship for fly ash and non-fly ash concrete with 19.0 mm (3/4 in.) nominal maximum-size aggregate. The increase in modulus of elasticity under these conditions with Class F fly ash is small. The study concludes that cement and aggregate characteristics will have a greater effect on modulus of elasticity than the use of fly ash (Cain 1979).

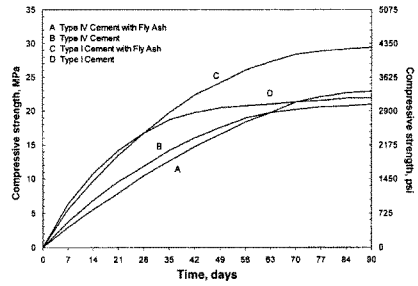

Fig. 3.1—Rate of strength gain for different cementitious materials: Class F fly ash (Samarin, Munn, and Ashby 1983).

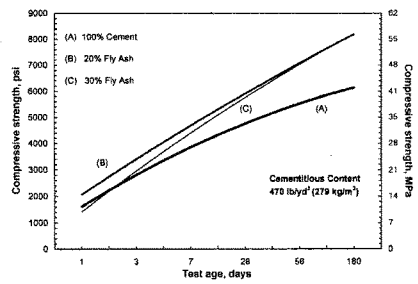

Fig. 3.2—Rates of strength gain of portland cement concrete and concrete in which part of the cement is replaced pound for pound with Class C fly ash (Cook 1983).

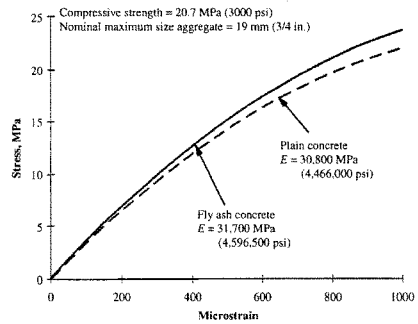

Fig. 3.3—Stress-strain relationship at 90 days (Tennessee Valley Authority 1981).

3.2.3 *Creep*—The rate and magnitude of creep strain in concrete depend on several factors, including ambient temperature and moisture conditions, strength of concrete, modulus of elasticity, aggregate content, the age of the concrete when load is applied, and the ratio of the sustained

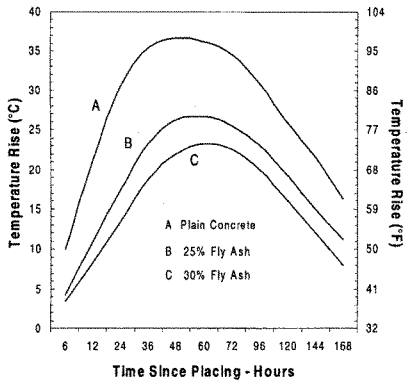

Fig. 3.4—Variation of temperature with time at the center of 15 m^3 concrete blocks (Samarin, Munn, and Ashby 1983).

stress to the strength at the time of loading. The effects of fly ash on creep strain of concrete are limited primarily to the extent to which fly ash influences the ultimate strength and the rate of strength gain. When constant load is applied to concrete with a given volume of cement plus fly ash at ages of 28 days or less, a higher creep strain occurs when compared to concrete having an equal volume of cement only. This is due to the lower strength of fly ash concrete at the time of loading (Lane and Best 1982). Lane and Best (1982), however, showed that concrete with fly ash proportioned to have the same strength at the age of loading as concrete without fly ash produced less creep strain at all subsequent ages. When specimens with and without fly ash are sealed to prevent moisture losses, simulating conditions in mass concrete, creep strain values are essentially equal after loading at an age of 1 year (Ghosh and Timusk 1981). When unsealed specimens of equal strength were loaded at 1 year, creep strain values for concrete containing fly ash were half those measured for concrete without fly ash.

Most investigations have shown that when concrete with and without Class F fly ash having equivalent 28-day strengths are loaded equally at the same age, the fly ash concrete will exhibit lower long-term creep due to the greater late-age strength common to most fly ash concrete. Yuan and Cook (1983) investigated the creep of concrete with Class C fly ash. With 20% replacement, creep was about the same; at above 20%, creep increased with increasing fly ash content.

3.2.4 *Bond*—Concrete bond or adhesion to steel is dependent on a number of parameters, including the surface area of the steel in contact with the concrete, the location of reinforcement, and the density of the concrete. Fly ash usually increases paste volume and reduces bleeding. Thus, the contact at the lower interface where bleed water can collect may be increased, resulting in an increased surface contact area. The development length of reinforcement in concrete is

Table 3.1—Heat of hydration of portland cement/ fly ash blends (Mather 1974)

Fly ash, % of cementitious material	Calories per gram		
	3 days	7 days	28 days
0	61	75	91
52	31	42	61
57	37	43	56
65	35	42	53
68	31	40	49
71	29	36	48

primarily a function of concrete strength. With proper consolidation and equivalent strength, the development length of reinforcement in concrete with fly ash should be at least equal to that in concrete without fly ash. These conclusions about concrete bond to steel are based on extrapolation of what is known about concrete without fly ash. The bonding of fresh concrete to existing concrete is minimally affected by the use of fly ash.

3.2.5 *Impact resistance*—The impact resistance of concrete is governed largely by the compressive strength of the mortar and the hardness of the coarse aggregate. The use of fly ash affects the impact resistance only to the extent that it affects the concrete's ultimate compressive strength.

3.2.6 *Abrasion resistance*—Compressive strength, curing, finishing, and aggregate properties are the major factors controlling the abrasion resistance of concrete (ACI 201.2R; ACI 210R). At equal compressive strengths, properly finished and cured concrete with and without fly ash will exhibit essentially equal resistance to abrasion.

3.2.7 *Temperature rise*—The chemical reaction of cement and water generates heat, which has an important bearing on the rate of strength gain and on early stress development due to differential volume change in concrete. Most of this heat is generated during the early stages of hydration of the alite (substituted C_3S) and C_3A phases of the cement. The rate of hydration and heat generation depends on a number of parameters: quantity, fineness, and type of cement; mass of the structure; method of placement; temperature of the concrete at the time of placement; and curing temperature. The heat generated can be reduced by using fly ash as a portion of the cementitious material in concrete, as shown in Fig. 3.4 (Samarin, Munn, and Ashby 1983; Mehta 1983). As the amount of cement is reduced, the heat of hydration of the concrete is generally reduced (Mather 1974). Values for heat of hydration at three, seven, and 28 days for blends of Type II portland cement and a Class F fly ash when the fly ash made up more than 50% by mass of the cementitious material were reported (Mather 1974) and are given in Table 3.1. Some Class C fly ashes, however, do contribute to early temperature rise in concrete (Dunstan 1984). When heat of hydration is of critical concern, the proposed concrete mixture should be tested for temperature rise.

3.2.8 *Resistance to high temperatures*—With respect to the exposure of concrete to sustained high temperatures, Carette, Painter, and Malhotra (1982) indicate that the use of fly ash in concrete does not change the mechanical properties of

concrete in relation to similar concrete containing only portland cement when exposed to sustained high-temperature conditions ranging from 75 to 600 °C (170 to 1110 °F).

3.2.9 *Resistance to freezing and thawing*—The resistance to damage from freezing and thawing of concrete made with or without fly ash depends on a number of parameters, including the adequacy of the air-void system, the soundness of the aggregates, age, maturity of the cement paste, and moisture condition of the concrete (Larson 1964). Care should be exercised in proportioning mixtures to ensure that the concrete has sufficient strength when first exposed to cycles of freezing and thawing while critically saturated. Concrete with or without fly ash should display a compressive strength of approximately 24 MPa (3500 psi) or more to ensure adequate protection. When compared on this basis in properly air-entrained concrete, investigators found no significant difference in the resistance to freezing and thawing of concrete with and without fly ash (Lane and Best (1982) for Class F fly ash and Majko and Pistilli (1984) for Class C fly ash). In addition, Halstead (1986) exposed fly ash concrete to freezing and thawing at very early ages and found no degradation of performance as compared with control concrete.

3.2.10 *Permeability and corrosion protection*—Concrete is permeable to water to the extent that it has permeable pore spaces through which water can move. Permeability of concrete is governed by many factors such as amount of cementitious material, water content, aggregate grading, consolidation, and curing efficiency. Powers, Copeland, and Mann (1959) showed that the degree of hydration required to eliminate capillary continuity from ordinary cement paste cured at standard laboratory conditions was a function of the water-cement ratio (*w/c*) and time. Required time ranged from 3 days at a *w/c* of 0.40 to 1 year at a *w/c* of 0.70.

$CaOH_2$ liberated by hydrating cement is water soluble and may leach out of hardened concrete, leaving voids for the ingress of water. Through its pozzolanic properties, fly ash chemically combines with $CaOH_2$ and water to produce C-S-H, thus reducing the risk of leaching $CaOH_2$. Additionally, the long-term reaction of fly ash refines the pore structure of concrete to reduce the ingress of water containing chloride ions. As a result of the refined pore structure, permeability is reduced (Manmohan and Mehta 1981; EPRI CS-3314).

Despite concern that the pozzolanic action of fly ash could reduce the pH of concrete, researchers found that an alkaline environment very similar to that in concrete without fly ash remains to preserve the passivity of steel reinforcement (Ho and Lewis 1983). Moreover, the reduced permeability of fly ash concrete can decrease the rate of ingress of water, corrosive chemicals, and oxygen.

The incorporation of fly ash in concrete results in very significant reductions in the chloride diffusion coefficient of cement paste, mortars, or concrete (Page, Short, and El-Tarras 1981; Li and Roy 1986; Thomas 1991; Dhir and Byars 1993; Kawamura and Torri 1989; Amoudi, Maslehudden, and Asi 1996). At early ages (such as 28 days), the difference in the diffusion coefficient of fly ash concrete and plain portland-cement concrete may be small, but the fly ash concrete undergoes very significant reductions in diffusion with age, and at ages beyond 1 year, it may have a diffusion coefficient many times lower than concrete without fly ash (Thomas and Bamforth 1999). Laboratory measurements made on concrete cores extracted from a 30-year-old hydraulic dam indicated the diffusion coefficient of fly ash concrete to be approximately one order of magnitude lower than that of similar concrete without fly ash in the same structure (Thomas and Bamforth 1999).

Ternary cement blends containing silica fume and fly ash can produce concrete with exceptional resistance to chloride-ion penetration (Thomas et al. 1999) as the silica fume affects a reduction in the early-age diffusion whereas the fly ash contributes to the ongoing reduction in diffusion as the concrete matures. Significant reductions in chloride diffusion coefficients and chloride permeability have been measured at both early and later ages when small amounts (8 to 12%) of ultra-fine fly ash were used as a cement replacement (Obla et al. 2000).

3.2.11 *Reduction of expansion caused by alkali-silica reaction (ASR)*—The reaction between the siliceous glass in fly ash and the alkali hydroxides in the hydraulic cement paste consumes alkalies, which reduces their availability for expansive reactions with reactive aggregates. The use of adequate amounts of some fly ashes can reduce the amount of aggregate reaction and reduce or eliminate harmful expansion of the concrete (Farbiarz and Carrasquillo 1987; Snow 1991). Data for mixtures containing eight different fly ashes with a cement of 0.66% Na_2O equivalent and a highly reactive aggregate are shown in Fig. 3.5(a) and (b). Often, the amount of fly ash necessary to prevent damage due to ASR will be more than the optimum amount necessary for improvement in strength and workability properties of concrete. Figure 3.5(b) illustrates the phenomenon of a pessimum level, where particular replacement levels of some high-alkali fly ashes increase the problem of ASR and higher replacement levels of the same fly ash reduce the problem of ASR (Farbiarz and Carrasquillo 1987). The pessimum level of a particular fly ash is an important consideration when selecting mixture proportions using potentially reactive aggregates. The available methods for preventing harmful expansion due to ASR in concrete containing fly ash when reactive aggregates are used include use of a pozzolan meeting ASTM C 618 requirements in a sufficient amount to prevent excessive expansion or the use of blended cement demonstrated to control ASR expansion that meets ASTM C 595 or C 1157 requirements (Portland Cement Association 1998). Several case studies of ASR in concrete suggest that some aggregates that pass the current informal, nonmandatory ASTM limits may cause deleterious reactivity in the course of a number of years, even with low-alkali cement (Farbiaz and Carrasquillo 1987; Snow 1991). Therefore, Class F fly ash at 20 to 25% mass replacement can be used as a general preventive measure. Thomas, Hooton, and Rogers (1997) recommend minimum levels of replacement of portland cement by fly ash, namely, 20 to 30%, depending on the composition of the fly ash, to control alkali-silica reactivity. Bérubé, Duchense, and Chouinard (1995) provide data on effectiveness of a Class C and F fly ash

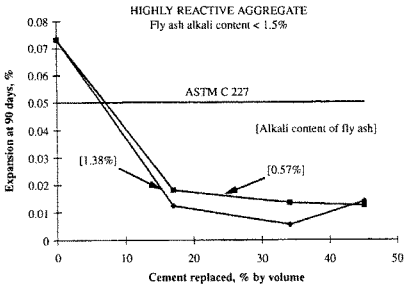

Fig. 3.5(a)—Mortar bar expansion versus percentage of cement replaced for all highly reactive aggregate mixtures containing fly ash with less than 1.5% alkali (Farbiarz and Carrasquillo 1987).

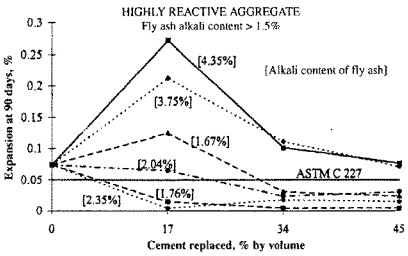

Fig. 3.5(b)—Mortar bar expansion versus percentage of cement replaced for all highly reactive aggregate mixtures containing fly ash with greater than 1.5% alkali (Farbiarz and Carrasquillo 1987).

in suppressing expansion due to alkali-silica reactivity using the accelerated mortar bar method, ASTM C 1260.

Lane and Ozyildirum (1999) reported on tests of four Class F fly ashes using mortars containing Pyrex glass as an aggregate and five portland cements having alkali contents ranging from 0.18 to 0.92%. Four of the fly ashes were tested at replacement levels ranging from 15 to 35% by mass of the total cementitious material. With cements of 0.40% alkali content and less, all replacement levels maintained expansion below 0.10%. With cements having alkali content above 0.60%, a replacement of 20 to 25% was necessary to control expansion, and this level of replacement appears to be effective with cements having alkali content up to 0.75 to 0.80%. One fly ash was used with one portland cement having alkali content of 0.64% to produce IP cements containing 18, 20, or 22% of fly ash. With these cements, expansion decreased as the proportion of fly ash increased. Expansion with the 18% blend exceeded 0.10%, whereas that of the 20 and 22% blends was maintained below 0.10%.

Lane (1999) provides results of tests of five fly ashes in mortar tests (ASTM C 441) with portland cements having alkali contents of 0.60, 0.75, or 0.92%, respectively, with the fly ashes being used variously as cement replacements of 15, 20, 25, or 35% by mass. Also provided are data on tests of concrete (ASTM C 1293) consisting of one portland cement and one fly ash with or without silica fume and slag. The alkali content of the cement was gaged to 1.25% as Na_2O equivalent.

Replacement levels for fly ash, when used as the only mineral admixture, were 15, 25, and 35% by mass. The coarse and fine aggregates were known to be deleteriously alkali reactive from previous tests. The fly ash was effective in controlling the expansion of the concrete at the 15% replacement level.

Thomas and Innis (1999) used the accelerated mortar bar tests (CSA A23.2-25A and ASTM C 1260) to evaluate the effect of mineral admixtures on expansion due to ASR. The evaluation comprised use of 70 different material combinations, including two low-calcium fly ashes (< 8% CaO), three intermediate-calcium fly ashes (8 to 20% CaO), and nine high-calcium fly ashes (> 20% CaO). For aggregates that were shown to be deleteriously reactive by both test methods, there was generally good agreement between the test results when the failure criteria used were expansion of mortar bars at 14 days greater than 0.10% and expansion of concrete prisms at 2 years greater than 0.049%. It was concluded that combinations of fly ash and reactive aggregates that pass the accelerated mortar bar tests can be used in the field with a very low and acceptable risk of deleterious expansion due to ASR. Using a highly reactive siliceous limestone as aggregate, the safe replacement level for the tested fly ashes ranged from 15 to 51% in the concrete prism test at 2 years and from 13 to 56% in the mortar test at 14 days.

Barringer (1999) describes use of combinations of fly ash as a mineral admixture and use of lithium salts to control the deleterious effects of ASR in concrete. The investigation included four Class F and one Class C fly ashes, five aggregate sources, and one Type 1-11 cement having an alkali content of approximately 0.55% as equivalent Na_2O. Lithium nitrate was used to provide water-soluble lithium when used as a supplementary admixture. AASHTO Test Method T303 was employed, comprising 121 sets of four mortar bars.

A Class F fly ash producing the greatest reduction of expansion was chosen for use with the lithium nitrate. The Class C fly ash and the blend of Class C and F fly ash did not perform well and were not included in tests involving the lithium salt. The combinations of lithium nitrate and Class F fly ash are more effective in the reduction of expansion than in lesser proportions that would be required with either material used singly.

If an aggregate produced expansion in this test of approximately 0.80% at 14 days, it is recommended that the initial trial batch include a 25% by mass Class F fly ash replacement of the total cementitious material or a combination of 15% of Class F fly ash and lithium nitrate at 100% of the manufacturer's recommendation.

3.2.12 *Sulfate resistance*—As a general rule, Class F fly ash can improve the sulfate resistance of concrete mixtures. The increase in sulfate resistance is believed to be due in part

to the continued reaction of fly ash with calcium hydroxides in concrete to continue to form additional C-S-H, which fills in capillary pores in the cement paste, reducing permeability and the ingress of sulfate solutions. The situation with Class C fly ash is somewhat less clear. Evidence suggests that some Class C fly ashes may reduce sulfate resistance when used in normal proportions. Mather (1982) found that several Class C fly ashes used at 30% replacement of several high C_3A cements made the system less sulfate resistant. Tikalsky, Carrasquillo, and Snow (1992); Tilkasky and Carrasquillo (1993); and Dunstan (1976) showed that concrete containing some high-calcium fly ashes are susceptible to sulfate attack, and generally, higher volumes of high-calcium fly ash mixtures have a greater susceptibility to sulfate deterioration.

Deterioration due to sulfate attack depends on chemical reactions that yield products of greater volume than those of the original reactants, resulting in expansion. A reaction occurs between the sulfates (usually of external origin, such as sulfate-bearing soils or sulfate-rich groundwater) and reactive phases, producing calcium sulfoaluminates. Damage due to this reaction can be reduced by minimizing the amount of C_3A in the concrete. Dikeou (1975) and Pierce (1982) established that certain fly ashes used in concrete under wetting-and-drying conditions greatly improve the sulfate resistance of concrete made with all types of cement. The cement and cement-fly ash combinations studied indicated a descending order of resistance to sulfate attack:

(a) Type V plus fly ash—most resistant to sulfate;
(b) Type II plus fly ash;
(c) Type V;
(d) Type II;
(e) Type I plus fly ash; and
(f) Type I—least resistant.

All fly ashes used in this study were Class F, and the ratios of the fly ash to total cementitious material by mass varied from 15 to 25%.

The sulfate resistance of fly ash concrete is influenced by the same factors that affect concrete without fly ash: curing conditions, exposure, and *w/cm*. The effect of fly ash on sulfate resistance will be dependent on the class, amounts, and the individual chemical and physical characteristics of the fly ash and cement used.

An indicator of the relative sulfate resistance of a fly ash is the *R* value developed by Dunstan (1980) and discussed by Pierce (1982). The *R* value is the ratio of the percentage of calcium oxide minus 5% (CaO% – 5%) to the percentage iron oxide (Fe_2O_3) in a fly ash, based on the bulk chemical analysis. More recent research (Mehta 1986; Tikalsky, Carrasquillo, and Snow 1992) has shown that the *R* value is not a definitive method for predicting sulfate resistance. They found that sulfate resistance depended on the amount of reactive alumina and the presence of expansive phases in the fly ash and was not as strongly influenced by Fe_2O_3 as indicated by the *R* factor. Generally, ASTM C 618 fly ashes with less than 15% CaO content will improve the sulfate resistance of concrete. Fly ashes with more CaO should be tested for sulfate expansion using ASTM C 1012 or USBR Test 4908.

The maximum sulfate resistance will be achieved in a given exposure and situation by employing a low *w/cm*, sulfate-resisting portland cement, and fly ash that exhibits good sulfate-resistance qualities. In attempting to select the fly ash that will give the maximum sulfate resistance to a concrete mixture, one should test blends of cements and fly ashes using ASTM C 1012. ASTM C 1157, the performance-based specification for hydraulic cements (which included blended cements), sets a limit on expansion at 6 months (tested in accordance with ASTM C 1012) of 0.10% for moderate sulfate resistance and 0.05% for high sulfate resistance. Fly ashes with large amounts of chemically active alumina can adversely affect sulfate resistance.

3.2.13 *Drying shrinkage*—Parameters influencing the drying shrinkage of concrete include fractional volume of paste, water content, cement content and type, and type of aggregate. Where the addition of fly ash increases the paste volume, drying shrinkage may be increased slightly if the water content remains constant. If there is a water-content reduction, shrinkage should be about the same as concrete without fly ash. Davis et al. (1937) studied different fly ash cement mixtures and found no apparent differences in drying shrinkage between concrete with up to 20% fly ash content and non-fly ash concrete. Dunstan (1984) and Symons and Fleming (1980) found that increased fly ash content resulted in slightly less drying shrinkage.

3.2.14 *Efflorescence*—Efflorescence is caused by leaching of water-soluble $CaOH_2$ and other salts to external concrete surfaces. The leached $CaOH_2$ reacts with CO_2 in air to form $CaCO_3$, the source of the white discoloration on concrete. The use of fly ash in concrete can be effective in reducing efflorescence by reducing permeability. Reduced permeability helps maintain the high-alkaline environment in hardened concrete. Certain Class C fly ashes of high alkali and sulfate contents, however, can increase efflorescence.

3.2.15 *Deicing scaling*—Scaling of concrete exposed to deicing chemicals occurs when immature or non-air-entrained concrete pavements are exposed to large quantities of deicing chemicals in a freezing-and-thawing environment. Concrete pavements and other flatwork containing fly ash that are exposed to deicing chemicals should be air entrained and allowed to reach a specified strength or maturity. Deicing chemicals are not recommended for use on any concrete during its first year of maturation. There is some laboratory research that indicates concrete containing 40% fly ash, as a percentage of the total mass of cementitious material, may be more susceptible to scaling (Gebler and Klieger 1986; Ernzen and Carrasquillo 1992; Johnston 1994).

3.2.16 *Expansion produced by free magnesia*—Liu, Tang, and Cui (1998) reported that the addition of fly ash or slag reduces the expansion of cements containing free magnesia (crystalline MgO), the effect increasing with an increase in the proportion of the fly ash. Fly ash was found to be more effective than slag in this regard.

Schlorholtz (1998) has summarized soundness characteristics of more than 5000 fly ash samples, primarily based on the autoclave soundness test (ASTM C 311). Expansive constituents in fly ash are free lime (CaO), free crystalline

magnesia (MgO), and C_3A. The autoclave test is especially sensitive to presence of free lime.

CHAPTER 4—CONCRETE MIXTURE PROPORTIONING

4.1—General

The most effective method to evaluate the performance of a given fly ash in concrete and establish proper mixture proportions for a specific application is a trial batch and testing program (ACI 211.1). Because different fly ashes have different properties and concrete requirements differ, fly ash and cement proportions cannot be prescribed for all materials combinations and requirements. Therefore, a series of mixtures should be prepared and tested to determine the required total amount of cementitious materials to obtain a specified strength with various percentages of fly ash (Ghosh 1976; Cook 1983). Fly ash is normally used at the rate of 15 to 35% by mass of total cementitious material. Larger proportions of fly ash can be used for mass concrete to reduce the likelihood of cracking upon cooling, improve sulfate resistance, reduce expansion caused by alkali-aggregate reaction or in other special applications (Malhotra 1984; Haque, Langan, and Ward 1984).

4.2—Considerations in mixture proportioning

Fly ash may be used in concrete either as a constituent of an ASTM C 1157 blended cement or as specified in ASTM C 595 for portland-pozzolan cement, Type IP (pozzolan-modified portland cement), Type I (PM), or it may be introduced separately at the concrete mixer. When used as part of blended cement, the proportions of portland cement to fly ash are fixed by the cement manufacturer. In the case of ASTM C 595, the proportions are given in the specification, while in ASTM C 1157 there are no composition limits in the specification. In mixture proportioning using Type IP cement or fly ash blended cement, the total amount of the blended cement to achieve the desired concrete properties needs to be determined. Fly ash blended cement is specified under ASTM C 1157 for general use, moderate heat and sulfate resistance, high early strength, low heat of hydration, high sulfate resistance, or low reactivity with alkali-reactive aggregate. When fly ash is batched separately, the individual proportions of cement and fly ash are selected, and their relative ratios should be adjusted as appropriate for each job situation.

Rahhal and Batic (1994) provide data on heat of hydration, flexural strength, and compressive strength produced by replacement of portland cement by 10, 20, 30, 50, 70, and 90% of fly ash at ages up to 180 days. The strength tests were performed on mortar specimens.

It is usually possible to proportion concrete mixtures for a particular strength level with a blend of cement and fly ash in which the volume of portland cement is less than it would be in similar strength mixtures not containing fly ash. If water-reducing admixtures are also used, the cement content is usually further reduced, as it is with non-fly ash concrete. Lovewell and Washa (1958), Cannon (1968), Shashiprakash et al. (1994), and others have suggested methods of proportioning concrete containing fly ash with and without chemical admixtures. When fly ash is used in the absence of a water-reducing admixture, indications are that the total volume of cementitious material used (cement plus fly ash) should exceed the volume of cement used in portland-cement concrete mixtures to produce equal early strength and equal slump. The total mass of the cementitious material and the optimum proportion of fly ash selected depend on the class and quality of fly ash; the type, quality, and alkali content of the portland cement; the presence of chemical admixtures; placement conditions; and parameters such as strength requirements, curing conditions, and weather conditions at the time of placement (Prusinski, Fouad, and Donovan 1993; Majko and Pistilli 1984).

The optimum use of fly ash and chemical admixtures may require adjustments to the ratio of cement to fly ash be made between winter and summer conditions. For example, in cold weather, a reduction in the fly ash percentage of the cementitious material may be prudent, or a change in the type of chemical admixture or dosage rate may be indicated to permit earlier finishing or form removal. Conversely, hot weather concreting provides greater opportunities for using high proportions of fly ash because higher curing temperatures tend to increase the relative strength of fly ash concrete compared with non-fly ash concrete at all ages, especially if long-term curing is provided.

Because the use of fly ash normally contributes additional volume to the concrete, adjustments are made to proportions. Following ACI 211.1, the volume of fine aggregates should be adjusted to compensate for this increase and for any change in volume of mixing water and air content. Ordinarily, a reduction in the mixing water demand can be expected when fly ash is used.

In ACI, *w/cm* is used to indicate water-cementitious material ratio, as opposed to *w/c* for water-cement ratio. This is a consistent approach because the fly ash in a blended cement meeting ASTM C 595 or C 1157 will be counted as part of the cement. In those cases where a maximum *w/cm* or a minimum cement content is specified or recommended, it is generally accepted practice to count the mass of the fly ash as part of the amount of cementitious material required when separately batched fly ash is used.

Where there is uncertainty concerning the proper *w/cm* to use in air-entrained concrete to attain frost resistance of concrete, it may be advantageous to specify a *w/cm* of 0.45 or lower as stipulated in ACI 211.1 for concrete exposed to cycles of freezing-and-thawing while saturated with water. A minimum strength level is needed to achieve a reasonably low porosity of concrete and thus minimize capillary continuity in the paste (Powers, Copeland, and Mann 1959; Buck and Thornton 1967). This is the same approach used in ACI 318 for concrete with low-density (lightweight) aggregate because it is difficult to calculate accurately the *w/cm* in such mixtures.

Similar to non-fly ash concrete, the water requirements of concrete containing fly ash can be reduced an additional 5 to 10% by using conventional water-reducing admixtures. Data reported by Vollick (1959) indicate that the amount of water reduction obtained in concrete incorporating fly ash can vary depending on the specific fly ash used and its proportion in

the concrete. The use of high-range water-reducing admixtures in concrete containing fly ash can lead to water reductions of 15 to 40%. The results appear to be largely dependent on type and dosage of admixture, chemical composition of the cement, and the cementitious material content of the concrete; generally, however, the admixture is more effective in concrete containing fly ash (Popovics 1993). Cementitious material contents in excess of 385 kg/m^3 (650 lb/yd^3) usually are required for 20% or greater water reduction. Ryan and Munn (1978) have reported that when a rapid rate of slump loss of concrete incorporating high-range water-reducing admixtures is experienced, it is not appreciably affected by the amount of fly ash used.

CHAPTER 5—FLY ASH SPECIFICATIONS, TEST METHODS, AND QUALITY ASSURANCE/CONTROL

5.1—Introduction

The ASTM specification for fly ash is ASTM C 618, and the relevant sampling and test methods are outlined in ASTM C 311. These standards are under the jurisdiction of ASTM Committee C09. ASTM C 618 was originally published in 1968 to combine and replace ASTM C 350 on fly ash and ASTM C 402 on other pozzolans for use as mineral admixtures. Standard ASTM C 311 for sampling and testing was originally published in 1953. Specifiers of fly ash should use the latest edition of ASTM C 618. The Canadian Standards Association has a published standard for fly ash—CSA A3000. This standard is very similar to ASTM C 618, with exceptions that will be noted in the following discussions.

The following discussion is based on the requirements of ASTM C 618 and C 311, which were in effect at the time this report was written. It is not intended to be a detailed review of all requirements. ASTM C 618 states that Class F fly ash is "normally produced from burning anthracite or bituminous coal;" and Class C fly ash is "normally produced from lignite or sub-bituminous coal." Many power plants blend various types of coals for power generation. Some fly ashes produced from sub-bituminous coals and lignite meet all the physical and chemical requirements of Class F and are thus marketed as Class F.

ASTM C 618 classifies fly ashes as Class F, which should have at least 70% sum of the oxides ($SiO_2 + Al_2O_3 + Fe_2O_3$), or Class C, which should have at least 50% of these oxides on chemical analysis. Class C fly ash generally contains more CaO than Class F and has cementitious and pozzolanic properties. The CaO content of Class C fly ash by chemical analysis is generally greater than 10% and may exceed 35%. The CaO is mainly combined in siliceous and aluminous glass.

5.2—Chemical requirements

As pointed out by Halstead (1981), early studies sought to relate fly ash performance to individual chemical oxide analysis results for silica, alumina, or iron oxide with little success. Today many, but not all, specifications have a minimum requirement for the sum of the oxides (Manz 1983). The intent is to ensure that sufficient reactive glassy constituents are present. A lower requirement is necessary for Class C because the CaO content may be substantial, thus making it impossible in some cases for the sum of the oxides to be 70% or more.

There has been a criticism of this sum of the oxides approach to fly ash classification, and it has been suggested that fly ash should be classified by its CaO content (Roy, Luke, and Diamond 1984). The problem is illustrated in the paper by Majko and Pistilli (1984), where properties of five ashes are reported. They referred to these ashes as Class C because of the good strength development obtained in concrete and CaO contents in the 9 to 25% range; however, four of the five fly ashes contained more than 70% ($SiO_2 + Al_2O_3 + Fe_2O_3$), which means they were chemically classified as Class F.

Virtually all specifications have a limit on the amount of what is reported as sulfur trioxide (SO_3) in fly ash. ASTM C 618 has a limit of 5.0% for both classes; other specification limits range from 2.5 to 12.0% (Manz 1983). The sulfate in fly ash and cement can affect the optimum amount of fly ash needed for maximum strength development and acceptable time of setting for the portland cement mixture in which it is used. An upper limit is considered necessary to avoid an excess of sulfate remaining in the hardened concrete that could contribute to detrimental sulfate attack.

Limits on moisture content of fly ash are necessary to ensure proper handling characteristics. Many ashes with a high CaO content will begin to hydrate in the presence of moisture. ASTM C 618 limits moisture to 3.0%; other specification limits are as low as 1.0%.

The maximum allowable LOI in ASTM C 618 is 6.0% for both Class C and F fly ashes. CSA A3000 allows 12% for Class F and 6% for Class C. Some specifiers modify this limit to a value lower than 6%, particularly where air-entrained concrete is involved. Many of fly ashes from base-load power plants are well below 6% LOI, mainly due to the efficiency of operation required to make economical use of coal as an energy source. In some special circumstances, a user may elect to use a fly ash with a higher LOI when acceptable laboratory or performance data are available.

5.3— Physical requirements

Fly ash fineness is specified in most cases by limiting the amount retained on the 45 μm (No. 325 [0.0018 in.]) sieve by wet sieving. Reactivity of fly ash has been found to be related directly to the quantity passing this sieve because the coarser particles generally do not react as rapidly in concrete. ASTM C 618 limits the amount retained to 34% for both Class F and C fly ashes. Some specifications classify fly ash by fineness grades based on different percentages retained on the 45 μm (No. 325 [0.0018 in.]) sieve. Control of fineness has occasionally been specified by surface area (air permeability). Surface area is normally reported by mass for portland cement and by volume for fly ash; the test results are not directly comparable. The relationship between fineness based on various densities is shown in Table 5.1.

The strength activity index with portland cement is considered only as an indication of reactivity and does not predict the compressive strength of concrete containing fly ash. It does

Table 5.1—Relationship between particle size and surface area

Mean particle diameter, μm	Surface area, m^2/m^3	Equivalent surface area, m^2/kg at various densities			
		2.0 Mg/m^3	2.5 Mg/m^3	3.0 Mg/m^3	3.15 Mg/m^3
2	3000	1500	1200	1000	950
3	2000	1000	800	670	630
4	1500	750	600	500	480
5	1200	600	480	400	380
6	1000	500	400	330	320
7	860	430	340	290	270
8	750	380	300	250	240
9	670	330	270	220	210

not necessarily bear any relation to the optimum proportion of fly ash for use in concrete.

In the past, the strength activity test with lime filled a need for more rapid results on strength performance (7 days rather than 28 days). More recent revisions of ASTM C 618 have included a 7-day strength activity test with portland cement. The 7-day C 618 test uses standard 23 °C (73 °F) laboratory curing temperatures, whereas CSA 3000 specifies curing at 65 °C (149 °F) for 7 days.

The water requirement of the mortar is used in the strength activity test to ensure that fly ash does not cause a large increase in mixing water demand. The ASTM standards limit the water demand of mortar mixtures when performing the strength activity test as described in ASTM C 311. The water requirement of mortar is measured as a percent of the water used in the reference portland-cement mortar. The allowable water content is limited to a maximum of 105% by ASTM C 618. Other ASTM specifications have lower limits with some as low as 95% maximum. Helmuth (1996) has proposed a new procedure to replace the present strength activity index test for fly ash in ASTM C 311.

Soundness is measured by autoclave expansion or contraction. Where the fly ash constitutes more than 20% of the cementitious material in the proposed concrete, the paste used for autoclave testing shall contain the anticipated percentage of fly ash. The test measures the delayed expansion that can occur if sufficient amounts of MgO are present in the concrete as periclase, or CaO as hard-burned crystalline lime (Halstead 1981; Pitt and Demirel 1983). Bobrowski and Pistilli (1979) found no correlation among autoclave expansion, SO_3 content, and concrete strength in their laboratory study. A length change of 0.8% is the maximum allowed by ASTM C 618.

The uniformity requirements given in ASTM C 618 limit the variation of density and fineness of the fly ash for shipments over a period of time. For fly ash used in air-entrained concrete, there is an optional limit on the variation of demand for air-entraining admixture caused by variability of the fly ash source. This requirement captures the quantity of air-entraining admixture required to produce an air content of 18.0% volume of mortar.

The optional multiple factor, applicable only to Class F, is calculated as the product of LOI (percent) and amount retained on the 45 μm (No. 325 [0.0018 in.]) sieve (percent). The maximum value of 255 restricts sieve residue (less than 34%) only when the LOI exceeds 6%.

The limit on the increase in drying shrinkage of mortar bars at 28 days should be applied only at the request of the purchaser to show whether the fly ash will cause a substantial increase in shrinkage in mortar bars as compared to bars with portland cement only.

Fly ash is considered to be effective in controlling ASR when its use leads to ASR resistance that is equal to or better than the use of a low-alkali control cement. Optional mortar-bar expansion tests should be requested if a fly ash is to be used with an aggregate regarded as deleteriously reactive with alkalis. ASTM C 618 limits the actual expansion of potentially reactive aggregate/paste combinations, whereas CSA A3000 determines the effect of fly ash in reducing expansion as compared to portland-cement-only samples.

Fournier and Malhotra (1999) provide a detailed review of laboratory test methods for evaluation of ASR of cement-aggregate mixtures, including recommendations regarding the use of fly ash as a supplementary material. For testing of laboratory specimens of concrete, ASTM C 1293 and CSA A23.2-14A are recommended. For testing of mortar specimens, ASTM C 1260 and CSA A23.2-25A are recommended.

5.4—General specification provisions

ASTM C 618 requires that the purchaser or an authorized representative have access to stored fly ash for the purpose of inspection and sampling. The fly ash may be rejected if it fails to meet any of the specified requirements.

5.5—Methods of sampling and testing

ASTM C 311 outlines the sampling and testing procedures of fly ash. For a number of test procedures, reference is made to other cement, mortar, or concrete tests. In some procedures, ASTM C 311 modifies proportions, preparation procedures, or test parameters needed to accommodate fly ash testing.

Either individual grab samples or composite samples are used, depending on the circumstances. The method provides detailed procedures for sampling from conveyor delivering to bulk storage, bulk storage at points of discharge, bulk storage by means of sampling tubes, and railroad cars or trucks.

The chemical analysis first requires the determination of moisture content by drying to constant mass and then determining the LOI from the resulting sample. The latter requires igniting the dried sample to constant mass in a muffle furnace at 750 ± 50 °C (1382 ± 122 °F) in an uncovered porcelain crucible (unlike the platinum crucible used for cement). Many of the required chemical determinations are then made using procedures that are the same as, or very similar to, those used in testing portland cement.

Physical tests on fly ash, including density and amount retained on the 45 μm (No. 325 [0.0018 in.]) sieve, are determined using test methods developed for portland cement. Soundness and strength activity testing procedures are specifically outlined in ASTM C 311, with reference to cement testing procedures where appropriate.

Of all the tests conducted, the two that are most difficult to obtain credible and repeatable results are fineness and

strength activity. The primary reason for variation in results reported for fineness is because test sieves are not precisely manufactured to exactly 45 μm (No. 325 [0.0018 in.]). The standard procedure calls for calibrating sieves using a portland cement reference sample and computing a correction factor for the sieve. Because the fly ash particles retained on the test sieve tend to be much larger than 45 μm (No. 325 [0.0018 in.]), sieves' large correction factors give inaccurate results. Sieves with small correction factors give more accurate results. In the strength activity index test with portland cement, results are highly dependent on the cement used by the laboratory. Because the performance of the cement is not controlled by the test method standards, tests conducted by different laboratories on the same fly ash sample may yield significantly different results. For many of the chemical and physical tests on fly ash contained in ASTM C 311, the precision and bias estimates have not been established.

5.6—Source quality control

Fly ash intended to be marketed as in conformance with ASTM C 618 should be produced under a quality-control program that is technically and statistically sound. The first recommended step in starting a fly ash quality-control program is to establish its quality history. The purpose of the quality history is to demonstrate that the fly ash consistently conforms to specification and uniformity requirements. For a new source of fly ash, at least 6 months of testing is recommended. This quality history should include monthly ASTM C 618 material certification and at least 40 individual test results for moisture, LOI, fineness, specific gravity, and SO_3. An analysis of these data by statistical techniques helps determine whether the proposed source of fly ash is suitable for the intended use (Dhir, Apte, and Munday 1988). After the quality history is established, the source should be tested at the frequency described in ASTM C 311, Table 1, to ensure continued conformance.

A quality-control program should be established for each individual source. Such programs can vary with coal type, collection systems, and other factors. The important characteristics of a particular fly ash source should be taken into account when developing a quality-control program. The quality-control program should consider both the fly ash characteristics and the specific requirements for its use in concrete. Testing for critical requirements may be needed more frequently than prescribed in ASTM C 311. All fly ashes do not have the same critical characteristics. These characteristics may not need to be included in every quality-control program. Periodic samples may also be detained and stored in the event that future testing and evaluation is desirable.

A quality-control program should maintain test reports on the fly ash to demonstrate product compliance to the physical, chemical, and variability requirements of ASTM or other project requirements, as well as monitor variability of critical characteristics. Statistical evaluations of the test data provide information on long-term variations.

ASTM C 311 provides for tests to be conducted on fly ash samples from established sources at a frequency not more than one test every 360 Mg (400 tons) for certain tests and not more than one test every 2900 Mg (3200 tons) for the remainder (testing frequency is higher for new sources). Some of the tests require at least 28 days to be completed. Consequently, it is often desirable to establish a quality-control program employing rapid-testing techniques as indicators of certain critical fly ash characteristics, in addition to ASTM compliance testing. Sampling and testing on a time schedule basis, in addition to the shipping basis prescribed by ASTM C 311, may be a useful part of the program.

Fly ash testing using rapid techniques is a basis for making continual judgments as to the selection of fly ash from a source and its suitability for a desired end use or directing it to alternative uses. (See Section 5.8 and the Appendix for descriptions of rapid tests.) In conjunction with the quality-control program, the fly ash supplier should be knowledgeable about power-plant operation and take action to exclude questionable fly ash when variations in the power-plant operation can influence fly ash quality. The chemical composition and fineness of fly ash are not likely to vary significantly at a power plant where the coal source is consistent, maintenance of the coal pulverizers and fly ash collectors is satisfactory, and the load on the power plant is fairly constant.

The performance of fly ash in concrete is related to the variation of properties with continuing shipments from the source of supply. Variations in other ingredients in the concrete will also affect the performance of the mixture. For Class F fly ash from a single coal source, the properties that are most likely to affect its performance in concrete are fineness, LOI, and autoclave expansion (Minnick, Webster, and Purdy 1971). Significant properties of Class C fly ash that affect performance in concrete include fineness, LOI autoclave expansion, and the amounts of SO_3, CaO, and alkalis present. Variability of fly ash color should also be monitored because changes in color can be important in architectural concrete applications. Fly ash color can also indicate changes in carbon content or power-plant burning conditions, which could alter the performances of the fly ash, especially in air-entrained concrete.

Schlorholtz and Dubberke (1995) report on use of x-ray fluorescence to determine the amount of fly ash in portland-cement fly ash mixtures, both in dry mixtures before batching and in hardened concrete and mortars.

Hooton and Rogers (1995) describe procedures using optical microscopy to estimate the fly ash content in hardened concrete.

McKerall, Ledbetter, and Teague (1981) have developed regression equations for fineness and specific gravity of fly ashes produced in Texas from sub-bituminous coal and lignite. These regression equations can be used to find close approximations of fineness, CaO content, and specific gravity given the results of the tests on the 75 μm (No. 200 [0.0030 in.]) sieve test and a CaO heat evolution test described in the Appendix.

5.7—Startup, oil, and stack additives

The fly ash distributor and user should be aware of changes in the ash properties that result from changes in power-plant operation, such as use of stack additives, flue-

gas conditioners, and changes in other aspects of production such as boiler startup (Ravina 1981). Changes in burning conditions and fly ash collection procedures at the power station can affect fly ash quality. The use of oil (to supplement burning) or stack additives, some of which may produce strong ammonia odors, needs to be detected rapidly. The addition of sodium sulfate to reduce blinding of precipitators can affect the time of setting of concrete, especially when certain admixtures are used. Liaison between the fly ash supplier and the power-station shift engineers, combined with frequent, rapid tests, should be used to detect problems early and divert questionable-quality fly ash to alternative destinations. When a coal-boiler unit is first fired, oil is often used to help initiate combustion, and the ash can contain hydrocarbon residues from the oil. In power plants where this is done during startup or under some other transient, short-term condition, the fly ash collected during these brief oil-burning periods should not be used in concrete. There are also some operations—in the UK, for example—where oil is burned with coal on a continuous basis. Fly ash from these operations may be suitable for concrete under certain circumstances, particularly in non-air-entrained concrete where control of admixture dosage is not a factor.

Materials are sometimes used by electric utilities during coal burning and fly ash collection to improve the efficiency of these operations. Materials termed "fireside additives" (EPRI CS-1318) are sometimes used in the burner to reduce SO_3 emissions, reduce corrosion and fouling, and improve the collection efficiency of the electrostatic precipitators. Fireside additives are used more in oil-fired boilers than in coal-fired plants.

Materials injected into the flue gas to enable the electrostatic precipitators to collect a greater proportion of the fly ash are termed "flue gas conditioners." Flue gas conditioners are often used in coal-burning power plants. When these types of materials are used, however, the fly ash may contain a small amount of substances such as magnesia, ammonium compounds, alkalies, or SO_3. Before using fly ash containing an additive, the variability of the amount of additive used in the power plant or present in the fly ash, and its effect in concrete, should be carefully evaluated.

5.8—Rapid quality-control tests

Fly ash collection at a base-load power plant usually continues around the clock, and because of limitations in storage capacity, decisions are made fairly rapidly concerning the probable quality of the fly ash so that material that does not meet requirements can be designated for other uses or directed to waste disposal. Some of the properties specified in ASTM C 618 and other characteristics are used in making these rapid fly-ash quality judgments. Several test methods have been devised to make daily, and in some cases hourly, quality estimates.

One or more of the rapid tests listed in the Appendix can be used as indicators of quality. The principal objective is to determine by rapid tests if the fly ash meets pre-established parameters for quality. These results should be supported by periodic comparison with results of standard tests of the fly ash and could be used in developing correlations between fly ash characteristics and concrete performance. The testing may be used by the fly ash distributor at the power plant or by the user to check shipments of fly ash for changes in properties or to predict air-entraining admixture dosage or strength performance in concrete. The rapid testing procedures discussed in the Appendix are:

1. Loss on ignition (LOI);
2. Carbon analysis;
3. Material retained on 45 μm (No. 325 [0.0018 in.]) sieve;
4. Air-jet sieving;
5. Air-permeability fineness;
6. Color;
7. Density (specific gravity);
8. Foam-index test;
9. Organic material;
10. CaO content;
11. Presence of hydrocarbons (startup oil); and
12. Presence of ammonia (precipitator additive).

CHAPTER 6—FLY ASH IN CONCRETE CONSTRUCTION

6.1—Ready-mixed concrete

A survey of the ready-mixed concrete industry in the U.S. in 1998 indicated that, of the companies who responded to the questionnaire, 94% use at least some fly ash, compared with 31% in 1983 (Portland Cement Association 2000). Approximately 55% of the concrete produced contained fly ash, compared with 46% in 1983. Some reasons for this substantial increase are:

(a) Technical benefits;

(b) Increased cost of energy to produce cement encouraged cost savings in concrete through the use of cement-fly ash combinations;

(c) The increased use of high-strength concrete of 52 MPa (7500 psi) or greater, which commonly requires the use of fly ash (Cook 1981; Albinger 1984);

(d) Increasing availability of fly ashes meeting applicable standards in the U.S. and Canada; and

(e) Governmental policies encouraging the use of fly ash to the maximum extent practicable.

Many concrete producers use fly ash to overcome deficiencies in aggregate grading or have developed mixtures specifically for pumping because concrete containing fly ash can pump higher and further at faster rates and with less segregation (Malhotra and Ramezanianpour 1994). Both lightweight and normalweight ready-mixed concrete containing 30% Class C fly ash were successfully pumped 305 m (1000 ft) vertically on a 75-story office tower in Houston, Tex. (Cook 1982).

Concrete with strengths up to 100 MPa (14,000 psi) in the field and higher in the laboratory, has been made with certain Class C fly ashes. The 72-story Interfirst Plaza in Dallas, Tex. contains approximately 60,000 m^3 (85,000 yd^3) of cast-in-place concrete using 30% Class C fly ash. Of this total, 15,700 m^3 (20,560 yd^3) was 70 MPa (10,000 psi) concrete with a reported average strength in excess of 83 MPa (12,000 psi) at an age of 56 test days (Cook 1989). Class F fly ashes are also used in high-strength concrete because of

the contribution to workability and long-term strength gain. Class F fly ash can contribute significantly to strength at 56 days.

Class F fly ashes are used to reduce the deleterious expansion associated with ASR. Aggregates that are otherwise unsuitable for use due to reactivity can be used when a fly ash known to adequately reduce alkali-silica expansion is used at the proper proportion in the concrete mixture.

Albinger (1984) stated that the decision to use or not use fly ash should be based on four factors:

1. Fly ash properties;
2. Effectiveness of the quality-control program of the supplier;
3. Ability to adjust to concrete changes, such as delayed finishability and increased air-entraining admixture demand; and
4. Cost effectiveness.

The cost of additional equipment to store and batch fly ash may be offset by the savings in material cost.

6.2—Concrete pavement

A 1992 EPRI study of 32 states found that all 32 states permitted the use of fly ash in pavement concrete and permitted the use of blended cements containing fly ash (EPRI 1992). Halstead (1981) summarized quality assurance and logistic problems relating to the use of concrete containing fly ash. Problems with the control of air entrainment and costs of transporting fly ash long distances were identified as the principal deterrents to more extensive use. Franklin (1981) reported on studies in the UK that considered the incorporation of fly ash in pavement concrete. In the U.S., the use of increased amounts of fly ash in highway construction is encouraged because of the availability of quality fly ash in most areas and governmental policies on funding as it relates to the use of fly ash to the maximum extent practical (Cain 1983). Hester (1967) reported on the use of fly ash in concrete pavement and structures in Alabama. This study found that for mixtures containing fly ash with reduced cement contents, higher flexural strengths were obtained. In Kansas, after 10 years of exposure and service, fly ash reduced, but did not eliminate, map-cracking and abnormal expansion in a 1949 test road (Scholer 1963; Stingley et al. 1960; Mather and Mielenz 1960). During the 1950s, Illinois, Nebraska, Wisconsin, Michigan, and Kentucky constructed experimental pavements with fly ash concrete to evaluate strength, crack resistance, placing and finishing qualities, and long-term wear resistance. All of these roads are reported to have performed well. Naik, Ramme, and Tews (1994) report that Class C and Class F fly ashes can replace portland cement in amounts as high as 50 or 40% by mass, respectively, to produce high-quality pavements.

6.3—Mass concrete

Mass concrete was one of the first applications in which fly ash was used in the U.S. Hungry Horse Dam in Montana, completed in 1953, contains over 2.3 million m^3 (3 million yd^3) of concrete and a total of 110,000 Mg (120,000 tons) of fly ash. From that time until 1970, at least 100 major locks and dams using fly ash were constructed under the direction of either the Corps of Engineers, the U.S. Bureau of Reclamation, the Tennessee Valley Authority, or private engineering firms. There are few mass concrete dams built in any part of the world that do not contain fly ash or natural pozzolan in the concrete (Hyland 1970). Large volumes of fly ash have also been used in roller-compacted concrete dams (Schrader 1982).

The use of fly ash can reduce thermal stresses by reducing the heat of hydration in mass concrete structures (Nasser and Marzouk 1979; Blanks, Meissner, and Rawhauser 1938; Carlson, Houghton, and Polivka 1979). By using fly ash concrete in massive structures, it is possible to achieve a reduction in temperature rise and reduce the risk of thermal cracking without incurring the undesirable effects associated with very lean mixtures, that is, harshness, bleeding, tendency to segregate, and tendency for increased permeability (Price 1982; Montgomery, Hughes, and Williams 1981). Improved sulfate resistance and reduction of expansion due to alkali-aggregate reaction provided by proper use of fly ash in the concrete mixture are other important considerations in the construction of mass concrete.

6.4—Roller-compacted concrete

Roller-compacted concrete (RCC) is used principally in mass concrete and pavements. ACI Committee 207 developed ACI 207.5R, which discusses its use in the construction and repair of dams. This form of concrete is transported and placed by dump truck or belt at the construction site, spread by conventional earth-fill placement methods, and then consolidated by rollers. Final consolidation is normally done by vibrating rollers. Construction time is very fast, the mixture is economical, and it achieves the strength of richer conventional mixtures.

ACI Committee 325 maintains report 325.10R on RCC pavements. RCC for pavement is a low-slump concrete with a 19 mm (3/4 in.) nominal maximum-size aggregate, low water content, and not less than 11% by mass of cementitious materials, of which 70% may be fly ash. The materials are mixed to a low slump consistency and laid down in lifts, usually by a lay-down machine. Rubber and steel-wheel vibrating rollers are used to consolidate the lifts. The pavement then receives a water cure or curing compound. Control joints are not normally provided. Uses include military vehicle, car, truck, aircraft parking areas, log sorting and storage yards, forestry and mine haul roads, and railroad unloading yards.

6.5—Self-consolidating concrete

Self-consolidating concrete (SCC) is a highly flowable yet stable concrete that can spread readily into place and fill formwork without consolidation and without undergoing significant separation of the material constituents. The use of SCC can provide a reduction in the labor demand needed for vibration and surface finishing, accelerate the placement rate, and secure superior surface quality. SCC can provide a homogeneous mixture of highly flowable concrete with good bonding properties, adequate structural performance, and proper durability (Khayat 1999). The proportioning of

SCC may vary based on specifics of a particular application and performance requirements such as flowability, resistance to dynamic and static segregation, and bleed characteristics. SCC is characterized by mixtures that provide good flowing characteristics while maintaining sufficient viscosity and cohesion to avoid material separation and segregation. These requirements can be achieved by proportioning the concrete with reduced amounts of coarse aggregate and higher amounts of fine material than usual. Another proportioning technique for SCC is to keep the usual concrete mixture proportions or use higher coarse-aggregate contents and use a viscosity-modifying admixture to provide stability and less segregation. Using either proportioning technique, higher proportions of fine materials such as cement and fly ash can be used to obtain the stability necessary to produce SCC.

Bouzoubaâ and Lachemi (2001) reported on SCC made with fly ash representing over 50% of the cementitious materials used in this product.

6.6—High-volume fly ash concrete

Haque, Langan, and Ward (1984) reported that high-volume fly ash (HVFA) concrete had emerged as a construction material in its own right and normally contains more than 40% fly ash by weight of total cementitious materials. Their report dealt with concrete suitable for concrete paving applications.

HVFA concrete may be defined as having a fly ash content of 50% or greater by mass of cementitious materials. Ramme and Tharaniyil (2000) described concrete with 37% fly ash as being HVFA. HVFA concrete can be considered to represent concrete containing higher percentages of fly ash than normal for the intended application of the concrete.

Dunstan (1981a,b) and Schrader (1982) reported on RCC mixtures using high volumes of fly ash for the construction of pavements and dams. This material maintains a low *w/cm* content and is batched to a dry consistency. Several researchers have reported on development of HVFA concrete of moderate to high slumps using high-range water-reducers and possessing suitable properties for commercial construction.

Mehta (1999) discussed CO_2 and the role it plays in global warming and illustrates the need to increase consumption of mineral admixtures to help offset the production of CO_2. Mehta and Burrows (2001) further discuss the role HVFA concrete can play in concrete to gain durability.

Attention to HVFA concrete has recently come from the U.S. Green Building Council through their program called LEED (U.S. Green Building Council 2001). The LEED program is intended to define green building criteria by providing a rational standard for measurement. The LEED program has developed a point system for project certification, which recognizes sustainable use of materials, land utilization, and design considerations. Points earned under various criteria lead to certification for 26 points or the enhanced levels of silver, gold, and platinum for point levels of 33, 39, and 52, respectively.

Fly ash is included in the LEED system in that it is defined as an environmentally free post-industrial recycled material. As such, its value in concrete is determined and combined with all other recycled materials in a structure. Higher-than-normal fly ash contents relative to portland cement enhance recycled material contents and gain certification points. The desire to increase recycled content value to achieve maximum recycled material content has led specifiers to require HVFA concrete mixtures in structural applications.

Manmohan and Mehta (2001) reported on HVFA concrete used for the seismic rehabilitation of Barker Hall at the Berkeley Campus of the University of California. Concrete for the structural wall contained 50% Class F fly ash of a total cementitious material content of 390 kg/m^3 (658 lb/yd^3). Concrete for the foundation contained 55% Class F fly ash of a total cementitious material content of 356 kg/m^3 (600 lb/yd^3). The mixtures contained moderate dosages of midrange water-reducing admixtures and exhibited better workability than conventional concrete at equivalent slumps. Formed surface finish was judged to be as good as or better than that achieved with conventional concrete. Compressive strength and set times were satisfactory for use in the project. Drying shrinkage was reported to be low, and satisfactory heat control was achieved as no thermal cracking has been exhibited.

Bilodeau, Malhotra, and Seabrook (2001) reported on the use of HVFA concrete in the Liu Centre in Vancouver, British Columbia, Canada. While concrete containing high-range water-reducer was previously considered mandatory, it was found that the use of high volume fly ash achieved adequate water contents 130 kg/m^3 (219 lb/yd^3) with normal dosages of conventional water-reducing admixtures. Strength adequate for form stripping was achieved at one day and met the structural requirements at 28 days of age. HVFA concrete was placed in the foundation and structural elements using conventional concreting practices.

Brooks and Fox (2003) reported on the GAP Embarcadero project in San Francisco, which consumed over 3820 m^3 (5000 yd^3) of concrete containing 50% class F fly ash and over 3440 m^3 (4500 yd^3) of concrete containing 33% Class F fly ash. The concrete mixtures were found to have satisfactory set time and strength gain for use in modern high-rise construction.

6.7—High-performance concrete

Fly ash is often an essential component in the production of high-performance concrete (HPC). HPC is defined by ACI 116 as "concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices."

HPC was employed for a major project in Salt Lake City, Utah, for which the concrete not only had to achieve a minimum specified compressive strength of 55 MPa (8000 psi) but more critically had to also achieve a modulus of elasticity of 48,280 MPa (7,000,000 psi). This HPC was used as a hollow core-stiffening component of the world's largest King Truss 562 Mg (620 tons). To achieve this performance, the concrete incorporated a very dense, stiff aggregate imported to Salt Lake City from Iron Mountain, Mo., and also used a substantial volume of Class F fly ash in addition to silica fume

and a high-range water reducer. This HPC mixture had to be capable of being pumped into the hollow portions of the truss. Success was achieved on all accounts (Snow 2001).

6.8—Bulk handling and storage

Because fly ash is normally of lower density than portland cement, its bulk density should be considered when ordering or taking inventory. Fly ash storage usually requires approximately 30 to 40% more volume per unit mass than does portland cement; a 100 Mg (110.2 ton) portland-cement bin will hold about 70 to 75 Mg (77.2 to 82.7 tons) of fly ash. Packaging in paper bags, "big bags," or other bulk containers may also reflect these differences in bulk density. The bulk density of fly ash in bins or silos is generally between 880 and 1280 kg/m^3 (55 and 80 lb/ft^3), whereas cement in bins and silos is generally between 960 and 1500 kg/m^3 (60 and 94 lb/ft^3). Both fly ash and cement may have lowered bulk density immediately after conveying (Strehlow 1973). Rail cars cannot carry as much mass of fly ash as of cement. Bulk pneumatic tank trucks that typically carry cement or fly ash are usually large enough in volume to receive a full legal load for over-highway delivery.

The spherical particle shape of fly ash and significant quantities of very fine grains mean that fly ash will require handling and storage facilities slightly different than those used for portland cement. When aerated, fly ash tends to exhibit very fluid handling characteristics, with an aerated angle of repose of 10 to 15 degrees. As a result, bins for storage of fly ash and transport systems (pneumatic or mechanical) should be well sealed to prevent leakage.

Bins and silos intended for cement can be used to store fly ash. Bins or silos should be large enough to receive at least two deliveries. The fluid nature of aerated fly ash can require slightly different unloading techniques than those used for portland cement. Due to the similar appearance of fly ash and cement, it is prudent to color-code and label the fill pipes or to take other precautions to minimize the possibility of cross contamination. Care should also be taken to clearly identify which storage compartments contain fly ash and establish proper materials-management procedures (Gaynor 1994). Bins should be completely cleaned when they are being converted to handle a different material. As with cement from different mills, fly ash from different sources should not be mixed in the same bin.

Because it is virtually impossible to detect fly ash contamination of a cement storage compartment by visually examining the cement as batched or the concrete as mixed, care in avoiding the intermingling of cement and fly ash is of great importance. A separate silo for fly ash is preferred. Segmented storage bins containing fly ash and portland cement (in adjacent bins) should be separated by a double bin wall with an air space between to prevent fly ash and cement from flowing together through a breach in a common wall. Otherwise, fly ash may move from one bin to the other through faulty welded connections or through holes caused by wear. If cement and fly ash are stored in different compartments of the same bin or silo and are separated by a common dividing partition, frequent inspections of the partition should be made.

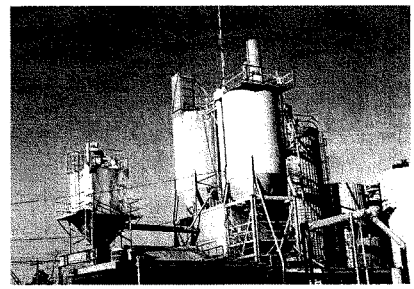

Fig. 6.1—Cement and fly ash silo with separate dust collection systems.

Each storage bin and silo should be equipped with a positive shutoff to control the flow of the fly ash to the weigh-batcher. Rotary valves, rotary-valve feeders, and butterfly valves are generally suitable for this purpose. A conventional scissor gate can be used if it is well maintained. Independent dust collectors on cement and fly ash bins, as shown in Fig. 6.1, are recommended to prevent cross contamination.

6.9—Batching

When batching fly ash and cement at a concrete plant, it is usually not necessary to install separate batchers. Fly ash and cement may have their masses determined cumulatively in the same batcher. Due to the lower density of fly ash, batchers should be sized adequately to handle larger volumes of cementitious material. Cement should be batched first so that accidental overbatching of fly ash will not cause underbatching of cement (Gaynor 1994). Care should be taken to accurately batch the correct amounts of both cement and fly ash because overbatching or underbatching can result in unacceptable variations in the properties of the fresh and hardened concrete. ASTM C 94 provides guidance for acceptable batching tolerances.

To transport fly ash from bin to batcher, methods such as gravity flow, pneumatic or screw conveyors, or air slides are most often used. The method depends on the location of the fly ash bin relative to the batcher. Fly ash from overhead storage is normally conveyed by gravity flow or an air slide. If the fly ash storage is at nearly the same level as the batcher, an air slide or a screw conveyor can be used (Fig. 6.2(a) and (b)). Because fly ash flows very easily, a positive shut-off valve should be installed to ensure that overbatching does not result from fly ash flowing through the air slide or screw when the device is stopped. Fly ash can be conveyed from lower level storage by pneumatic conveyor. During storage and batching, fly ash should be protected from moisture (in the air, from condensation, or from inclement weather) to avoid problems in handling and changes in the fly ash characteristics.

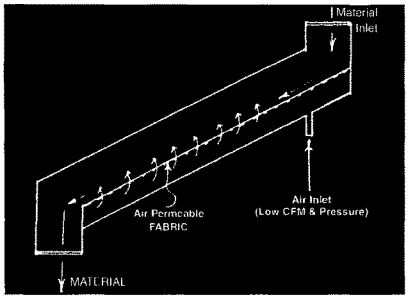

Fig. 6.2(a)—Schematic of an air slide.

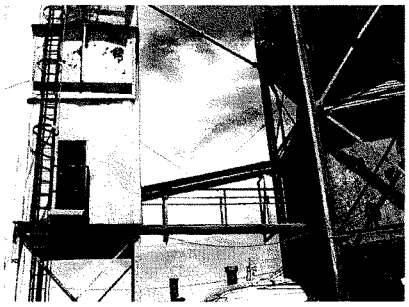

Fig. 6.2(b)—A screw conveyor for transporting fly ash.

CHAPTER 7—FLY ASH IN CONCRETE PRODUCTS

7.1—Concrete masonry units

The manufacture of concrete masonry units usually involves a dry, harsh concrete mixture consolidated in molds with mechanical force. When demolded, these units maintain their shape during handling and transportation into a curing environment. Fly ash has found widespread use in the manufacture of these products as a cementitious material and filler.

Curing methods for masonry units include autoclave and atmospheric-pressure steam. Manufacturers using either curing system can incorporate fly ash in their concrete mixtures and obtain the required strength. In addition, they obtain better mold life, and products with improved finish and texture and sharper corners. Fly ash gives added plasticity to the relatively harsh mixtures used in concrete masonry units (Belot 1967). Autoclave curing is still used to manufacture high-quality masonry units. Concrete masonry units cured in autoclaves show an early strength equivalent to that of 28-day moist-cured strength and reduction in volume change in drying (Hope 1981). The process uses temperatures of 135 to 190 °C (275 to 375 °F) and pressure of 0.52 to 1.17 MPa (75 to 170 psi). These conditions allow for the use of fly ash in amounts up to 35% for Class C fly ashes and 30% of the cementitious material for Class F fly ashes. Percentages greater than these can result in efflorescence and reduced strength with Class C fly ash, and color variation and reduced strength with Class F fly ash. Particular care should be taken to ensure that the fly ash meets the soundness requirement of ASTM C 618, especially when the fly ash will constitute more than 20% of the total cementitious material in the product. While these values are usual, individual mixtures should be evaluated to determine the optimum level of fly ash that can be used.

Atmospheric-pressure steam curing is usually carried out in insulated kilns. The exact curing temperature is a function of the materials and the amount of fly ash used. Up to 35% for Class C and 25% for Class F fly ashes by mass of total cementitious material have been used satisfactorily with a curing temperature above 71 °C (160 °F). Drying shrinkage of atmospheric-pressure steam-cured concrete units can be reduced by the addition of fly ash. Optimum curing temperature is 82 to 93 °C (180 to 200 °F).

Accelerated curing techniques require a period of preset before the concrete products are subjected to elevated temperatures. When fly ash is used in conjunction with cement, it may be necessary to extend the preset period to avoid damage to the end products.

Proportioning of mixtures for the manufacture of concrete masonry units is not an exact science. Conditions can vary widely from plant to plant. When proportioning mixtures, concrete product producers should check the grading and types of aggregates, cements, equipment, and kiln temperatures, and then adjust trial batches with various amounts of fly ash to achieve specific technical or economic objectives (Valore 1970).

7.2—Concrete pipe

The manufacture of concrete pipe is accomplished by two different processes: one that uses extremely dry concrete mixtures and the other that uses more fluid concrete mixtures. Dry-cast concrete pipe uses mechanical compaction, vibration, or both, to consolidate the dry concrete mixture into a form that is removed as soon as the casting is finished. With removal of the form, the green pipe is carefully transported to its place of curing. Accelerated, atmospheric curing is normally used to obtain early-age performance.

Wet-cast concrete uses more fluid concrete placed and compacted in a form that remains around the pipe until certain levels of performance are achieved. Wet-cast pipe may be manufactured by the spinning process to remove excess water and air to produce high strength, high density, and low permeability.

Fly ash has found widespread use in the manufacture of concrete pipe as a cementitious material and as a filler to enhance quality and economy. Because properly proportioned mixtures containing fly ash make the concrete less permeable, concrete containing fly ash may be more resistant to weak acids and sulfates (Davis 1954; Mather 1982). Factors pertaining to the life of concrete pipe exposed to sulfate attack include the type of cement, class of fly ash, quality of concrete, bedding and backfill used, and sulfate concentration.

Dry-cast concrete pipe mixtures without fly ash typically use greater cement contents than necessary for strength to obtain the required workability. In a packerhead pipe casting operation, concrete with a very dry consistency and low water content is consolidated in a vertical pipe form using a revolving consolidation tool. Vibratory pipe processes use mechanical vibration to consolidate dry concrete into a form. The cement content can be reduced by replacing some of the cement with fly ash. Fly ash is used as a cementitious material and as a filler to provide added workability and plasticity. Equipment used in pipe production may last longer due to the lubricating effect of the fly ash. The use of fly ash can increase the cohesiveness of the no-slump, freshly placed concrete facilitating early form stripping and movement of the product to curing.

Other benefits attributed to the use of fly ash include a reduction in the heat of hydration of concrete mixtures containing fly ash, which can reduce the amount of hairline cracks on the inside surface of stored pipe sections (Cain 1979). Concrete mixtures containing fly ash also tend to bleed less, which is beneficial in wet-cast pipe.

Current ASTM specifications for the production of concrete pipe require the use of fly ash meeting the provisions of ASTM C 618, Class F or C. These specifications allow for the use of portland-pozzolan cement meeting ASTM C 595 requirements, containing a maximum of 25% fly ash by mass. Where fly ash is used separately, it is limited between 5 and 25% of total cementitious material. The cementitious material content for concrete for pipe production should not be less than 280 kg/m^3 (470 lb/yd^3). The concrete mixture shall also have a maximum *w/cm* of 0.53.

7.3—Precast/prestressed concrete products

Precast concrete products can be produced with or without reinforcement. Reinforcement includes fibers, conventional reinforcing steel, and prestressing steel tendons, either pretensioned or post-tensioned, or combinations thereof. By definition, precast concrete products are cast and cured in other than their final position (ACI 116R). This facilitates the use of reusable forms that, for economy, are cycled as rapidly as possible. These concrete products generally achieve their competitive positions in the marketplace by using a limited number of forms with a rather short production cycle. Normal production schedules use one set of forms per day; however, 10 to 12 h schedules are common. Accelerated curing is used to enhance early-age concrete performance for handling, shipping, and product use.

Concrete mixtures for these products are proportioned for high levels of performance at early ages. Compressive strengths of 24 to 34 MPa (3500 to 5000 psi) are usually required at the time of form removal or stripping. These early concrete strengths are generally achieved with cement contents of 355 to 445 kg/m^3 (600 to 750 lb/yd^3). Conventional and high-range water-reducing admixtures are often used for workability at very low water content. Non-chloride accelerating admixtures are also sometimes used for decreased times of setting. Under these conditions, fly ash generally has not been considered as an appropriate ingredient for concrete mixtures; however, conditions appear to be changing toward the use of fly ash in these applications.

Responding to a questionnaire distributed in August 1986, 77 members of the Prestressed Concrete Institute (PCI) responded to questions about their use of fly ash in prestressed concrete products (Shaikh and Feely 1986). Of the total, 32% indicated that they were currently using fly ash in their products, 9% had used fly ash but had stopped, and 58% had never used fly ash. Of those responding that they were using fly ash, the average fly-ash content as a percentage of total cementitious material was 19%, with the lowest being 12% and the highest 30%. Of the respondents who have discontinued the use of fly ash, 86% stated that low initial strength gain as a problem. Other problems experienced in using fly ash were lack of consistency of fly ash, slump loss, and difficulty in obtaining uniform mixing. It was felt that additional studies should be carried out to define the effect of fly ash on some of the critical parameters such as early strength gain, creep, shrinkage, permeability, and elastic modulus.

Favorable results were obtained by Dhir, Zhu, and McCarthy (1998) in investigations on concrete containing fly ash at ages from 18 h to 1 year measuring strength development (compressive and tensile) and deformation behavior (elastic, creep, and shrinkage) using Class F fly ash. The amount of fly ash used as a percentage of total cementitious material ranged from 22 to 45%, and the ratio (by mass) of Class F fly ash added versus cement replaced ranged from 1.23:1 to 1.59:1. Concrete containing fly ash should perform as well as, or better than, concrete containing only rapid-hardening cement. Another investigation was conducted with Class C fly ash and a Type I cement to determine the extent of strength gain obtainable (Naik and Ramme 1990). Cement replacements of 10 to 30% were investigated with fly ash replacing cement at a ratio of 1.25:1 using an established nominal 34.5 MPa (5000 psi) concrete mixture without fly ash. This study concluded that high-early strength concrete can be produced with high replacement of cement by fly ash for precast/prestressed concrete operations. This work was done with the cooperation of two different prestressed concrete operators. One of the operations uses fly ash as 20% of the cementitious material in daily work year around.

In cases where fly ash can not be economically justified as a cementitious material, it may be used to enhance other product features. Fly ash used in precast concrete products improves workability, resulting in products with sharp, distinctive corners and edges; fly ash may also improve flowability, resulting in products with better surface appearance. Better flowability and workability properties achieved by using fly ash are particularly desirable for products with intricate shapes and surface patterns and for those that are heavily reinforced. Additionally, an appropriate fly ash may be used in areas with potentially reactive aggregates or unknown sulfate conditions to provide protection against these types of long-term durability problems.

The most common reasons for using fly ash are the savings in cost of materials and labor that can generally be achieved and improved quality of concrete. Fly ash may make sense

for the reasons noted in the previous programs. In any case, proportions and curing procedures should produce adequate early strength or the turnaround time on forms or molds will be increased (Ravina 1981). In general, fly ash becomes more desirable for applications where early strength is not a critical parameter. This usually occurs only when the specifications prohibit form removal before specified ages.

7.4—No-slump extruded hollow-core slabs

Pretensioned hollow-core structural slabs are produced using no-slump concrete. It is consolidated and shaped as it passes through an extrusion machine. The particle shape of the coarse aggregate and the amount of fine aggregate are very important to workability. Fly ash is usually added to increase the workability of these dry, harsh mixtures.

CHAPTER 8—OTHER USES OF FLY ASH

8.1—Grouts and mortar

According to ACI 116R, grout is "a mixture of cementitious material and water, with or without aggregate, proportioned to produce a pourable consistency without segregation of the constituents; also a mixture of other composition but of similar consistency." Its primary purpose is to permanently fill spaces or voids. Mortar contains the same basic ingredients, but with less water so that a less-fluid consistency is achieved. Mortar is used primarily in masonry construction. The benefits derived from using fly ash in grouts and mortars are much the same as those obtained when fly ash is used in concrete (Bradbury 1979). These include economy, improved workability, lower heat of hydration, reduced expansion due to ASR, reduced permeability, and improved sulfate resistance. The flowability of grout is generally improved, particularly under pressure, due primarily to the favorable particle shape and lower specific gravity of the fly ash particles, which tend to stay in suspension longer and reduce segregation (Hempling and Pizzella 1976).

Common uses of grout include:

(a) Preplaced aggregate concrete where grout is injected into the void of previously placed coarse aggregate to produce concrete (ACI 304R);

(b) Contact grouting either under machinery to fill the space between a base plate and substrate concrete or between the top surface of concrete placed or pumped under existing concrete or rock, as in tunnel linings;

(c) Providing support for deep mine applications;

(d) Curtain grouting where very fluid mixtures (often without aggregate) are used to fill voids in rock foundations;

(e) Soil stabilization to fill voids in soil or between soil particles to densify and generally improve its load-carrying capacity;

(f) Slab jacking to raise and realign concrete slabs or structures that have settled; and

(g) Underwater placing and slope protection where grout is generally injected into preplaced inflatable cloth blankets that are flexible enough to conform to the surrounding contour to completely fill the void and provide complete contact.

8.2—Controlled low-strength material

Controlled low-strength material (CLSM) is discussed in ACI 229R and is often known by other names such as flowable fill, lean-mix backfill, controlled-density fills, flowable mortar, K-krete™, fly ash slurry, and flowable fly ash. CLSM normally consists of fly ash, cement, water, and fine aggregate. It may include coarse aggregate, lightweight aggregate, and admixtures such as air-entraining admixtures, water-reducers, and high-range water-reducers. The U.S. Department of Transportation Federal Highway Administration (FHWA) has issued a Technical Report, "Fly Ash Facts for Highway Engineers," FHWA-SA-94-081, which includes flowable fill applications, mixture proportions, and specification requirements.

8.3—Soil cement

ACI 230.1R explains soil cement in detail. Soil cement is used as a base for road, street, and airport paving. It provides uniform, strong, solid support for paving. It is used for slope protection for dams and embankments and liners for reservoirs, lagoons, and other channels. It has been used as a mass placement for dikes, foundations, and coal-containment berms in power plants. It has also been used in rammed-earth wall systems and as regular backfill material. Fly ash can be used in soil cement as a cementitious material. Usually, the cementitious material content is 4 to 16% of the dry weight of soil, of which any portion of the cementitious material can be fly ash. The use of self-cementing coal fly ash as the sole stabilizing agent is addressed in *1999 Coal Combustion Byproduct—Production and Use* (American Coal Ash Association 2000).

8.4—Sulfur concrete

Sulfur concrete is reported in ACI 548.2R. Sulfur concrete construction materials are now used in many specialized applications throughout industry and transportation. They are used primarily in areas where conventional materials like portland-cement concrete fail, such as acidic and saline chemical environments. These new construction materials are thermoplastic and achieve compressive strength in excess of 62 MPa (9000 psi) within 1 day of casting. The materials are impervious to moisture permeation and extremely resistant to attack by mineral acids and salts. ACI 548.2R includes historical background information and a guide to sulfur concrete construction and reports the use of fly ash as a fine mineral filler.

8.5—Plastering

ACI 524R covers the use of current materials and methods for plastering. Recommendations for producing good portland-cement-based plaster are given. Various mixtures characteristics, procedures, and alternates with advantages and disadvantages are discussed. Fly ash and other minerals can be added to a plaster mixture to improve sulfate resistance.

8.6—Cellular concrete

ACI 523.3R presents information on materials, fabrication, properties, design, and handling of cellular concrete with oven-dry densities greater than 800 kg/m^3 (50 lb/ft^3) and aggregate concrete with oven-dry densities greater than 800 kg/m^3 (50 lb/ft^3) but whose compressive strengths are less than

17.24 MPa (2500 psi). The density range of such concrete is generally used for thermal and sound insulation fills for roofs, walls, and floors. At the higher densities, cellular concrete is used in cast-in-place walls, floors, and roofs, and also for precast elements such as wall and floor panels. Pozzolans are used in normally cured, low-pressure steam-cured, and high-pressure steam-cured (autoclaved) lightweight aggregate and cellular concrete. Fly ash and natural pozzolans used should conform to ASTM C 618. A thorough description of the use of pozzolans in autoclaved lightweight products can be found in ACI 516R.

8.7—Shotcrete

ACI 506R provides information on material and properties of both dry-mix and wet-mix shotcrete. Most facets of the shotcrete process are covered, including application procedures, equipment requirements, and responsibilities of the shotcrete crew. Preconstruction, prequalifying, and acceptance testing of workers, material, and shotcrete are also considered. ACI 506R recommends that cement conform to ASTM C 150 or ASTM C 595. In ASTM C 595, the blending or intergrinding of a pozzolan in which the pozzolan constituent is between 15 and 40% mass of the portland-pozzolan cement is allowed.

8.8—Waste management

"Wastecrete" is the term given to the solidification and stabilization of hazardous waste with fly ash or with various combinations of cementitious materials. Hazardous wastes include manufacturing wastes streams, incinerator ash, landfill waste, mine tailings, radioactive wastes, and superfund wastes. Properties associated with this use of fly ashes are:

1. Reduction in permeability;
2. pH adjustment;
3. Pozzolanic activity;
4. Economy;
5. Free water; and
6. Ease of application.

Fly ash immobilizes many toxic heavy metals as relatively insoluble hydroxides or carbonates. This immobilization is accomplished by maintaining a pH in the range between 8 and 12. Other additives are sometimes used to treat the wastes and decrease leachability of various organic compounds. When solidifying hazardous wastes with fly ash, treatability studies should be conducted on the combined wastes and solidifying agents so that appropriate results are obtained (Roy, Eaton, and Cartledge 1991; Roy and Eaton 1992).

"Oilcrete" is a term given to the solidification and stabilization of various oil wastes with fly ash and other solidifying agents. The oil wastes include oil-based drilling fluids, water-based drilling fluids, and listed or unlisted refinery sludges. Fly ash has been used for many years to stabilize oil wastes in Louisiana and Texas; recently, these techniques were modified for use in the Western and Plain states.

In-place treatment of oil-reserve pits is a relatively simple procedure accomplished by mixing fly ash by pneumatic injection or mechanical methods. The oil waste and fly ash mixture hardens to form a low-permeability, solid mass. Generally, 0.14 MPa (20 psi) will support 10 m (30 ft) of overburden, but some agencies require 1.4 MPa (200 psi), which will necessitate the use of additional fly ash. After stabilization, oilcreate is covered and the natural grade restored.

8.9—Cements and lime

The use of pozzolans such as fly ash Class F, Class C, uncalcined natural pozzolan, and calcined natural pozzolans are allowed in the production of cement, the blending of cement, and use with lime. Information in detail can be found in ASTM C 595, ASTM C 1157, and ASTM C 593.

8.10—Fillers

There are a number of publications regarding using fly ash/pozzolans as filler in non-concrete applications: asphalt roofing products, cast aluminum, plastics, ceramics, paints, and stone matrix asphalt.

1. *Use of Fly Ash in Asphalt Roofing Products* discusses mineral stabilizer, or filler, as a major raw material requirement in the manufacture of the majority of prepared asphalt roofing products such as shingles (Pike and Shaw 1995);
2. "Microstructure and Properties of Cast Aluminum-Fly Ash Paritcle Composites" presents the microstructure and selected properties of cast aluminum-silicon allow matrix-fly ash particle composite (Rohati et al. 1993);
3. "Fly Ashes as Modifiers for Low Cost Polymeric Materials" discusses polymeric materials used in electrotechnical field due to their insulation, lightness, and chemical inertia features (Quattroni, Levita, and Marchetti 1993);
4. "Fly Ash a 21st Century Ceramic Filler" discusses how fly ash generated in coal-fired power plants is an abundant mineral resource that has been successfully used in protective coatings as a very hard and inert filler pigment (Mainieri and Growall 1996); and
5. *Guidelines for Materials, Production, and Placement of Stone Matrix Asphalt (SMA)* tells how SMA is a relative new paving mixture in the U.S., which shows promise as a tough, stable, rut-resistant surface mixture in certain applications (IS 118 1994).

8.11—Oil-well cementing

The Halliburton Company introduced the use of fly ash in the cementing of wells to the oil industry in 1949. The advantages of using fly ash portland-cement mixtures in wells are fundamentally the same as for concrete, except the conditions of placement and curing are variable and the nomenclature of properties are expressed somewhat differently. In some instances, deep wells have been cemented by mixtures of fly ash and hydrated lime together with an activator that is used as a catalyst for setting (Smith 1956). The fly ash used in oil-well cementing shall conform to ASTM C 618 according to the oil-well cementing industry and American Petroleum Institute (API) "Specification for Material and Testing for Well Cement" (American Petroleum Institute 1990).

CHAPTER 9—REFERENCES

9.1—Referenced standards and reports

The standards and reports listed below were the latest editions at the time this document was prepared. Because

these documents are revised frequently, the reader is advised to contact the proper sponsoring group if it is desired to refer to the latest version.

American Association of State Highway and Transportation Officials (AASHTO)

T303 Accelerated Detection of Potential Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction

American Concrete Institute

116R Cement and Concrete Terminology
201.2R Guide to Durable Concrete
207.5R Roller-Compacted Mass Concrete
210R Erosion of Concrete in Hydraulic Structures
211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
229R Controlled Low-Strength Materials
230.1R State-of-the-Art Report on Soil Cement
304R Guide for Measuring, Mixing, Transporting and Placing Concrete
318 Building Code Requirements for Structural Concrete
325.10R Report on Roller-Compacted Concrete Pavements
506R Guide to Shotcrete
516R High-Pressure Steam Curing: Modern Practice, and Properties of Autoclaved Products
523.3R Guide for Cellular Concrete Above 50 pcf and for Aggregate Concretes Above 50 pcf with Compressive Strengths Less than 2500 psi
524R Guide to Portland Cement Plastering
548.2R Guide for Mixing and Placing Sulfur Concrete in Construction

ASTM International

C 94 Standard Specification for Ready-Mixed Concrete
C 115 Test Method for Fineness of Portland Cement by the Turbidimeter
C 150 Standard Specification for Portland Cement
C 204 Test Method for Fineness of Portland Cement by Air Permeability Apparatus
C 311 Method for Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete
C 430 Test Method for Fineness of Hydraulic Cement by the 45-μm (No. 325 – 0.0018 inches) Sieve
C 441 Test Method for Effectiveness of Mineral Admixtures or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete due to the Alkali-Silica Reaction
C 593 Standard Specification for Fly Ash and Other Pozzolans for Use With Lime
C 595 Specification for Blended Hydraulic Cements
C 618 Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
C 1012 Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution
C 1157 Standard Performance Specification for Hydraulic Cement
C 1260 Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
C 1293 Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction

Electric Power Research Institute

SC-2616-SR Workshop Proceedings: Research and Development Needs for Use of Fly Ash in Concrete
CS-1318 Electric Utility Use of Fireside Additives
CS-3314 Testing and Correlation of Fly Ash Properties with Respect to Pozzolanic Behavior
ID-1006565 Coal Ash Carbon Removal Technologies
TR-101686 Institutional Constraints to Coal Ash use in Construction

U.S. Bureau of Reclamation

USBR 4908 Length Change of Hardened Concrete Exposed to Alkali Sulfates

Canadian Standards Association

CSA A3000 Cementitious Materials Compendium
CSA A23.2-14A Potential Expansivity of Aggregates (Procedure for length change due to alkali-aggregate reaction in concrete prisms)
CSA A23.2-25A Test Method for Detection of Alkali-Silica Reactive Aggregates by Accelerated Expansion of Mortar Bars

These publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

Electric Power Research Institute
Box 50490
Palo Alto, CA 94303

U. S. Bureau of Reclamation
P.O. Box 25007
Denver, CO 80225

Canadian Standards Association
5060 Spectrum Way
Mississauga, Ontario
Canada L4W 5N6

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APPENDIX—RAPID QUALITY-CONTROL TESTS

A.1—Loss of ignition

The test, in accordance with ASTM C 311, involves drying to constant mass for moisture content. If the moisture content is known to be low, however, a quick LOI can be run in less than an hour using a preheated muffle furnace, a crucible providing greater surface area, and a cooling unit that increases heat loss from the sample. In this case, any moisture would be included in the ignition loss value.

A.2—Carbon analysis

Carbon content of fly ash is related to LOI, but it is not a totally comparable measurement. A rapid Leco furnace method is available to make a total carbon determination. Gebler and Klieger (1983) tested a number of Class F and Class C fly ashes using this procedure. In all cases, the carbon determination was somewhat less than the ASTM C 311 LOI, but the correlation between the two test values was very good.

A.3—Material retained on 45 μm (No. 325 [0.0018 in.]) sieve

The ASTM C 311 procedure generally involves at least 2 h of drying of the residue on the sieve after the wet-sieving operation. A hot plate or higher oven temperature, however, can be employed to obtain more rapid results; this method is preferred for Class C fly ash to minimize weight gain during drying due to hydration.

Wet sieving of fly ash may produce errors if the fly ash contains significant water-soluble materials or materials that react rapidly with water.

A.4—Air-jet sieving

Alpine air-jet sieve equipment is available that may not provide accurate information because the sieving operation is conducted using air instead of water, and the material retained on the sieve can be weighed directly. Other rapid particle size distribution instruments (such as ATM sonic sieve equipment) are also available that can be employed to indicate changes in the particle size distribution of fly ash.

A.5—Air-permeability fineness

The ASTM C 204 method can be used to measure the specific surface of fly ash within 10 min. Specific surface is not currently specified in ASTM C 618; however, it has been cited in previous versions of the specification. It is a fast procedure that may be used to detect changes in fly ash fineness from given source, particularly changes at the lower end of the size distribution.

A.6—Color

Color changes can be checked by comparing the color of the fly ash with that of a reference fly ash. Spread the two fly ashes side by side on a white surface and compare the color under daylight or a controlled light source. If necessary, a piece of clear glass can be an indicator of change in fly ash properties, and it may cause changes in concrete color—important in architectural uses. A concrete producer can save a jar sample from each fly ash delivery for a period of several months. A comparison of color of a new delivery with previous deliveries from the same source can provide an immediate indication of changed conditions.

A.7—Density (specific gravity)

Changes in density or the amount of cenospheres that float on water in another fairly rapid procedure that may be used in identifying changes. The density procedure for fly ash referenced in ASTM C 311 is C 188. The measurement can be made in an hour or two; however, excellent temperature control is required for good accuracy.

A.8—Foam-index test

Foam-index values are based on the amount of air-entraining admixture needed in a slurry of 50 mL of water, 4 g of fly ash, and 16 g of cement to produce a layer of foam just covering the surface of liquid in a 473 mL (16 oz) wide-mouthed jar after vigorous shaking (Meininger 1981; Gebler and Klieger 1983). There is a good relationship between the minimum amount of admixture in this test necessary to cause foam to cover the surface, without discontinuities, and the admixture dosage needed in concrete containing the same sources of fly ash and cement.

A.9—Organic material

Analysis of fly ash by the Wakeley-Black soil testing method is one approach that has been used to estimate the easily oxidizable organic matter or carbon in fly ash using sodium dichromate and sulfuric acid (Meininger 1981; Gebler and Klieger 1983). Those fly ashes with greater oxidizable material measured in this manner tended to require higher admixtures demand and caused more loss of air in concrete.

The University of Maryland method used in these fly ash studies provides a value that is increased by a factor to give an estimate of total oxidizable matter. The factor used for soils may not apply to fly ash so the direct amount of oxidized material should be used. Previous work on the effect of organic material in cement also showed that it can have an effect on air entrainment (Greening 1967).

A.10—CaO content

Measurement of heat evolution when fly ash is reacted with an appropriate chemical solution is described by McKerall, Ledbetter, and Teague (1981). In addition to the cited reference, some trails using automated equipment have been used. Future development of this type of equipment may provide indicators of CaO content, which can be obtained in less than 15 min.

A.11—Presence of hydrocarbons (startup oil)

Mix the fly ash with tap water and note the presence of a black film on the surface of the water.

A.12—Presence of ammonia (precipitator additive)

Add 20 to 50 g fly ash to tap water that includes cement or other alkaline material. Cover the bottle and mix. Open the bottle to detect ammonia odor (Ravina 1981).

William H. Gehrmann
President
Headwaters Resources, Inc.

Testimony
Before the Subcommittee on Rural Development, Entrepreneurship and Trade
Committee on Small Business
United States House of Representatives

"Coal Combustion Byproducts: Potential Impact of a Hazardous Waste Designation on Small Businesses in the Recycling Industry"
July 22, 2010

Thank you Mr. Chairman. Honorable Members of the Committee, I am Bill Gehrmann, President of Headwaters Resources, Inc., on whose behalf I am testifying today. I have more than 25 years experience in the management and marketing of coal combustion products, which are often generically referred to as "coal ash." My experience includes managing the promotion, sale and distribution of coal ash; development of new products utilizing coal ash, the construction and operation of hazardous and non-hazardous waste landfills, and the design and operation of material handling systems.

Headwaters Incorporated is a New York Stock Exchange company that provides an array of energy services. We are a leading provider of pre-combustion clean coal technologies for power generation, including coal cleaning, upgrading and treatment. We are the nation's largest post-combustion coal product manager, operating on more than 100 power plant sites nationwide. We have built a construction materials manufacturing business and incorporated coal ash in many of our products. We are currently commercializing technologies for upgrading heavy oil and have entered the biofuels market by constructing an ethanol production facility utilizing waste heat from an existing coal fueled power plant in North Dakota. Headwaters is also active as both a technology provider and a project developer in the field of coal-to-liquid fuels.

As a manager and marketer of coal ash, Headwaters touches every link in the chain of activity that makes beneficial use of the material possible. Small businesses comprise a significant portion of many of the links in this chain. My testimony today is intended to describe that chain of activity and the probable effects of a "hazardous waste when disposed" determination on each.

There are many compelling reasons to use coal ash instead of simply disposing it. The most obvious reason is conservation of natural resources. When coal ash is used rather than disposed, other native natural resources are conserved by reducing the production of materials that coal ash is replaces. Additionally, landfill space is conserved.

The effect of off-setting environmental impacts from other industries is especially apparent in the case of utilizing coal fly ash to replace cement in the production of concrete. For every ton of fly ash used to replace a ton of cement, nearly a ton of carbon dioxide is avoided from the cement production process. In this manner, the coal ash reuse industry is currently responsible for well over 10 million tons per year of annual greenhouse gas emissions reductions. (It is important to remember that coal fly ash is a byproduct of generating electricity. The greenhouse gas emissions associated with consuming coal will exist whether or not the fly ash is used to replace cement. Accordingly, fly ash use in concrete has long been recognized by all credible sources as a legitimate and effective large volume approach to reducing greenhouse gas emissions.)

But the benefits of using coal ash are not limited to the environment. Many products made with coal ash are of higher quality than products made without it. For instance, concrete made with coal fly ash is stronger and more durable than concrete made with cement alone. Engineers and builders also use coal fly ash to address specific materials problems, such as the presence of reactive aggregates or soils, to further improve concrete durability.

There are economic benefits to consider, as well. More durable structures last longer, decreasing maintenance and replacement costs, while further conserving natural resources. Additionally, coal fly ash is less expensive than other technologies available to address engineering issues such as reactive aggregates.

Other witnesses will testify regarding the human health and environmental safety of using coal ash, but it is important to emphasize two facts. First, based on its mineral characteristics, coal ash does not approach the levels that would qualify it as a "hazardous waste" under federal law. Second, the mineral characteristics of coal ash are often strikingly similar to that of the materials coal ash is replacing when it is used.

The existence of all of these environmental, performance and economic advantages does not mean that using coal ash is easy. Significant investments must be made to be able to transport and deliver materials to users at the minute they need it. Users must be educated in how to properly utilize the materials and they must understand the materials' safety and efficacy. Today's utilization rate for coal ash in the United States is approximately 44 percent and is the product of more than three decades of efforts to identify and meet the needs of the following participants in coal ash use:

1. Ash Producers. Typically utilities that consume coal to generate electricity, ash producers are faced with a decision regarding whether to dispose of coal ash or reuse it. Disposal activities are usually carried out on the power plant site by the utility itself or a contractor. Since reusing coal ash is not considered a core function by most utilities, specialized "ash marketers" are usually engaged to perform those services on behalf of the utilities that desire a reuse program.

If coal ash is designated a "hazardous waste" when disposed, ash producers will be faced with this question: "This material is 'hazardous' on my own property, so am I willing to take the risk of turning it over to a third party who will market it into applications where it will be used in thousands of locations in the surrounding community?" Coal ash sales revenues are not a significant source of income for most ash producers and many ash producers will simply pass increased disposal costs on to their customers in the form of higher prices for energy. Rather than risk additional future changes in regulation or lawsuits from enterprising personal injury attorneys, ash producers will likely elect to choose disposal over reuse. If that is the case, all of the small businesses about to be described will be left without a product to use.

2. Ash Marketers. These marketing companies range in size from very small (fewer than 5 employees) to medium sized divisions of larger companies. They carry out a range of activities that includes transporting ash to customer markets and storing it prior to distribution, providing education and technical support to product specifiers and end users, and providing quality control and customer service.

   If coal ash is designated a "hazardous waste" when disposed, ash marketers will face significant challenges in both the operations of their businesses and the outlook for customer relations.

   From an operational point of view, the U.S. Environmental Protection Agency claims that it will continue to support "legitimate" beneficial uses in the event of a "hazardous when disposed" designation, but cannot answer ash marketer questions such as these: If a small quantity of ash spills during delivery, does it become a 'hazardous waste' for disposal purposes? Does ash transportation and handling equipment need to be placarded as 'hazardous waste?' What additional training and personal protection equipment will be required for workers handling coal ash? What will happen to insurance and Workers Compensation rates? All of these questions, and there are many more, represent significant challenges for small and mid-sized businesses.

   From a customer relations point of view, many of the same operational questions will afflict the concrete producers and manufacturers that purchase coal ash from marketers – making them reluctant to continue using the material. Coal ash users have alternatives to using coal ash and can choose to eliminate its use.

3. Ash Technology Developers and Providers. A segment of the coal ash industry comprised primarily of small businesses can be described as ash technology developers and providers. Some of these companies are concerned with developing and deploying technologies for improving the quality and marketability of coal ash for traditional uses. One example is providers of technologies to remove residual carbon from fly ash in order to make it suitable for use in concrete. Other small companies are engaged in developing and deploying technologies for utilizing coal ash in new applications.

Examples include fly ash brick manufacturers or technologies that may use fly ash in sequestering greenhouse gas emissions.

If coal ash is designated as "hazardous waste" when disposed, ash technology providers and developers will face significant new customer objections and barriers to raising capital for development activities. Even in advance of enactment of any rule, companies in this sector have reported slowdowns in financing activities and customer purchases attributed to the regulatory uncertainty presented by EPA's draft rulemaking proposal.

4. Product Specifiers. A key link in the coal ash industry chain is comprised of entities that never actually purchase or handle the material, but play a pivotal role in whether or how it gets used. Product specifiers – including architects, engineers and their industry standards setting organizations – create specifications that either require or prohibit the use of coal ash. In determining specifications, these entities consider the effect of the material on finished product performance and human health and safety.

   If coal ash is designated a "hazardous waste" when disposed, product specifiers will face the same potential operational and liability concerns previously described for ash producers and marketers. Additionally, standard setting organizations such as the American Concrete Institute and ASTM have already indicated in letters to EPA that their obligations to protect human health would require them to remove from specifications any materials that are determined to be a hazardous substance in another setting.

5. Ash Users. Ash users are the entities that actually use coal ash as an ingredient in other products. Examples include ready mixed concrete producers and other product manufacturers, many of which are small businesses with less than 50 employees.

   If coal ash is designated a "hazardous waste" when disposed, ash users will face the same potential operational and liability concerns previously described for ash producers and marketers. In order to avoid added operational costs and potential liabilities, many users may elect simply to quit using coal ash. In almost every example of coal ash use, coal ash replaces another material that is accessible without a hazardous regulatory stigma. In cases where coal ash is used for specific engineering purposes, such as mitigating reactive aggregates in concrete, competitive products are available at much higher costs, but without potential liabilities.

   In its proposed coal ash disposal rule, the EPA cites examples of other industries in which materials designated as "hazardous" have been successfully recycled. None of EPA's examples, however, are analogous to coal ash – which is used without undergoing additional processing and is placed in products that come into direct contact with end users. EPA's examples also concern materials that are sold to sophisticated users accustomed to handling hazardous materials. Coal ash users do not have this level of experience and capability.

6. End Users. End users are the people who actually purchase and use finished products containing coal ash – in other words, anyone who uses a home, school, office building, driveway, etc. This final link in the coal ash industry chain is the least likely to be informed regarding characteristics of materials and the most likely to become confused and concerned by a "hazardous when disposed" regulatory designation.

   If coal ash is designated a "hazardous waste" when disposed, end users will likely demand products that contain no "hazardous" substances. This phenomenon is already being seen even in advance of EPA enacting any new rules. The drumbeat of the phrase "toxic ash" in news stories about EPA's rulemaking effort has resulted in many ready mixed concrete producers receiving calls from customers asking for fly ash to be eliminated from their concrete. The Los Angeles Unified School District has eliminated coal ash from its concrete specification pending resolution of the EPA rulemaking. New examples are arising every day.

   Manufacturers of competitive products are also beginning to step in to fan flames of doubt for end users. Advertisements warning against products containing "hazardous waste" have appeared. Potentially even more damaging is "behind the scenes" misinformation by competitors that will be impossible to identify or rebut.

In meetings with me and with other representatives of the coal ash industry, EPA officials have indicated that they support the beneficial use of ash. But actions speak louder than words and EPA has done precious little to demonstrate support for legitimate coal ash use. To the contrary, EPA has unilaterally and without explanation removed its Coal Combustion Products Partnership program information from its web site. End users seeking information from the EPA about coal ash are now greeted with the single statement: "The Coal Combustion Products Partnerships (C^2P^2) program Web pages have been removed while the program is being re-evaluated."

The benefits of coal ash use are well known to EPA and have been presented in detail in two former Reports to Congress. Also contained in those reports were analyses of "barriers" to greater coal ash utilization. "Regulatory barriers" have been identified by EPA itself as one of the key reasons coal ash use rates don't go even higher.

EPA's 2010 rulemaking has already become a significant regulatory barrier by introducing the possibility of "hazardous when disposed" regulation. As discussed previously, end users are already reacting negatively to the mere presence of EPA's proposal. I find it ironic that such a regulatory barrier has been created primarily over a dispute by regulators regarding who should enforce regulations. The actual engineering standards for disposal facilities are essentially the same under EPA's hazardous and non-hazardous proposals. EPA's hazardous proposal appears calculated primarily to get federal enforcement authority over the regulatory program. EPA appears to be willing to sacrifice a substantial and beneficial industry merely to obtain greater regulatory influence.

Headwaters and the coal ash industry are not opposed to increasing the regulation of coal ash disposal. Our trade organization, the American Coal Ash Association, has even passed a formal resolution supporting national standards for coal ash disposal. But these increased disposal standards can and must be established without designating coal ash as a "hazardous waste" in any setting.

The best course of action for our nation's environment is one that encourages safe and beneficial coal ash use as a preferred alternative to disposal. Whatever material remains unused can then be disposed in a safe and effective manner. The "hazardous when disposed" approach proposed by EPA will have exactly the opposite effect – reducing coal ash use activities and thereby creating more waste to be disposed.

Thank you for the invitation to testify and for your interest in this important topic. I would be happy to answer any questions.

HOUSE SMALL BUSINESS

SUBCOMMITTEE ON

RURAL DEVELOPMENT, ENTREPRENEURSHIP AND TRADE

July 22, 2010

STATEMENT BY

ROBERT A. GARBINI, PE
PRESIDENT

ON BEHALF OF

THE NATIONAL READY MIXED CONCRETE ASSOCIATION (NRMCA)

Chairman Shuler, distinguished Members of the Subcommittee, thank you for the invitation to testify on behalf of the National Ready Mixed Concrete Association (NRMCA), and thank you for holding this important hearing on Coal Combustion Byproducts (CCBs): Potential Impact of a Hazardous Waste Designation on Small Businesses in the Recycling Industry. I am Robert Garbini, the President of the NRMCA. Founded in 1930, NRMCA's mission is to provide exceptional value to our members by responsibly representing and serving the entire ready mixed concrete industry through leadership, promotion, advocacy, education and partnering. For the committee, as a matter of scale, ready mixed concrete consumes 75% of all of the portland cement used in this country. We represent over 1,500 manufacturers of concrete and the 50 state affiliate organizations. It is important to note that approximately 85% of NRMCA's members are small businesses with less than $30 million in sales annually. Many of our small business members are the classic family-owned and run ready mixed concrete companies that represent the vast majority of this industry.

Concrete is the most widely used construction material in the world and is produced and consumed in every part of our country. In fact, no construction takes place without use of some concrete products. Based on NRMCA's latest Industry Data Survey, it is estimated that U.S. ready mixed concrete industry revenues exceeded $25 billion in 2009, a down year; and an estimated 130,000-145,000 people directly derived their livelihood from the ready mixed concrete industry. The manufacturing of ready mixed concrete is part of the larger concrete construction industry which employs over two million people. Seasonally adjusted annual construction spending is currently $869 billion.

With regard to fly ash the ready mixed concrete industry is the largest beneficial user of fly ash. The use of fly ash in concrete is widespread, and has been for years. In 2008 alone, the concrete industry used 15.8 million tons of fly ash in the manufacturing concrete; fly ash is by far the most widely used supplementary cementing material (SCM). A 1998 survey of ready mixed concrete producers by the Portland Cement Association (PCA) and NRMCA showed that over 55% of all ready mixed concrete contained fly ash at an average of 20% by weight of total cementitious content.

Fly ash is used in combination with portland cement to impart beneficial qualities to concrete. The environmental benefits of using these industrial byproducts in concrete results in longer lasting structures and reductions in the amount of waste materials sent to landfills, raw materials extracted, energy required for production, and air emissions, including carbon dioxide. The overall carbon footprint of ready mixed concrete containing fly ash is considerably reduced and it is an important factor supporting sustainable construction practices. There are also economic benefits to using fly ash in concrete. Fly ash is significantly less expensive than portland cement and therefore reduces the materials cost of concrete while providing enhanced performance. Although the concrete industry uses significant amounts of fly ash, it is estimated that there is still about 42 million tons of all fly ash land filled annually. Although not all fly ash that ends up in landfills is of sufficient quality for use in concrete, it is estimated that the concrete industry could increase its current use to above 30 million tons per year by 2020 which would reduce the concrete industry's carbon footprint by 20%. This would help the ready mixed concrete industry attain the Environmental Protection Agency's (EPA) and Obama administration's desired goal of reducing, in part, CO_2 emissions by at least 17% by 2020. This however, assumes that the

distribution system exists to maintain its use as an economically viable option and evolving regulations on power generation facilities do not adversely impact the ability of fly ash to meet current standards for use in concrete.

Based on the ready mixed concrete industry's extensive use of and reliance on fly ash in concrete and, after examining EPA's proposed rule, we have determined that a Resource and Conservation Recovery Act (RCRA) Subtitle C designation for coal combustion byproducts bound for disposal while retaining the Bevill exemption for beneficial use will lead to the following unintended consequences for small ready mixed concrete businesses:

1. Increased production costs: The cost of making concrete will likely increase whether or not fly ash is beneficially used in concrete. If a concrete producer chooses to continue to use fly ash despite the risks, they will likely pay more for the fly ash since both EPA and the electric utilities have suggested the additional cost for disposal will be passed onto consumers, including concrete producers. For those producers who choose to discontinue the use of fly ash, they will be forced to use more costly portland cement and other SCMs. In both cases, the cost of making concrete will likely rise. If fly ash is replaced with cement, the material costs of concrete are expected to increase by an average of 10%. Unemployment among small business concrete producers is currently around 20%. The resulting increased material costs will make it harder for small businesses to maintain their current staffing levels.
2. Increased liability: Ready mixed concrete producers are unsure about the regulatory status of small amounts of fly ash that ultimately will be comingled within their waste stream during the day-to-day operations of manufacturing ready mixed concrete or the

cost associated with handling the fly ash. The industry is averse to taking risks due to potential liability of handling a labeled hazardous waste and therefore may chose to no longer use fly ash. A possible remedy for this would be a liability exemption for beneficial users. Without an exemption the potential costs associated with such liability will likely have devastating consequences on the small businesses in the ready mixed concrete industry.

3. Stricter state laws for beneficial use: We suspect that many states will establish new laws that further limit the beneficial use of fly ash. For example, the state of Maryland, in a recent proposed rule, requires any product containing fly ash to be disposed of in a facility authorized to accept fly ash. If the EPA declares fly ash disposal as subtitle C, then states may change their regulations to force concrete crushed after its service life from demolition of buildings and pavements, or from waste stream of new construction, to be handled in this manner. In their proposed ruling, EPA has stated that waste streams from beneficial use will be characterized for disposal based on its characteristics. However, there is no assurance that states will follow this line of thinking. If fly ash concrete bound for disposal is classified as hazardous or special waste, then ready mixed concrete producers are unlikely to use fly ash in their concrete.
4. Eliminating the use of fly ash concrete: It has taken several decades of education to convince engineers and architects to specify fly ash in concrete. We suspect that the stigma and fear of liability will drive specifying engineers, architects and end users to disallow the use of fly ash in concrete. We also fear that the perception of the general public will not distinguish the difference between the characterization of a waste bound for disposal and that diverted for beneficial use. There is no amount of proper education

or marketing that will relieve beneficial users and specifiers and/or consumers of concrete from the negative impact or stigma associated with manufacturing or using a product that incorporates an ingredient that is characterized as a hazardous waste. Our concern is that fly ash use will significantly decrease in concrete, and result in driving up the cost in the manufacturing process for small businesses.

5. Impact to durable infrastructure: From the 1920s, fly ash has been recognized as a valuable addition to ready mixed concrete to enhance the service life of our nation's dams, highways, bridges, homes and buildings. It is recognized as the most effective means of ensuring durable infrastructure and to support the use of some marginal regional materials with enhanced performance. The current state of our failing infrastructure would be increased at least two fold without the judicious use of fly ash in concrete. This will result in concrete construction that is less durable, less sustainable and lead to higher life-cycle costs.

Due to the complexity of EPA's proposed rule on disposal of CCB's, NRMCA currently is surveying its members to get a broader view of possible implications. We anticipate having the survey responses completed and returned by the end of August. NRMCA has respectfully requested EPA extend their comment period by 120 days to provide ample time for our members to complete the survey and also give us time to analyze and compile survey responses. NRMCA anticipates responding to EPA's proposed rule with evidence derived from our survey results from those who understand the issue most on behalf of the largest segment of beneficial users – the ready mixed concrete small businesses. The survey will quantify the potential path the industry will take based on the perception of a stigma associated with the proposed classification

of fly ash for disposal as a special waste and the unintended consequences on beneficial use in ready mixed concrete.

In summary, NRMCA believes that a Subtitle C designation is only to the detriment of the ready mixed concrete industry, especially its small businesses. Thank you for hearing my concerns, on behalf of the ready mixed concrete industry. NRMCA looks forward to working with the distinguished Members of the Subcommittee on this and other important issues related to small businesses.

Testimony Regarding Proposed Coal Ash Regulation

Docket ID No. EPA-HQ-RCRA-2009-0640

Good Morning,

Bross Construction is a multi-faceted family owned construction company established in 1966. My father, two brothers and myself own and operate the company. Many of the construction services we provide involve the use of ready mix concrete, in fact we own several ready mix plants which incorporate the use of flyash. The ability to use coal ash as an additive in our ready mix concrete has lowered the cost to the consumer for concrete projects. Projects ranging from highways to driveways. From an employer perspective, the lowered costs of producing ready mix concrete allow us to invest scarce resources elsewhere, such as employee benefits, updated equipment and an expanded work force. At a time when our economy is so unstable and millions of Americans are unemployed an increased cost for any product is simply untenable.

The proposed regulation of coal ash as a hazardous material for coal producing plants while at the same time exempting that designation for those who wish to use it in ready mix concrete seems counter productive. The world in which we live and do business is very sensitive to any designation of any product as "hazardous". While the general public might not be aware of this "fine line" designation; those who put together requirements for projects will understand the designation and will be very reluctant to open themselves to any kind of "claim" by our trial attorney population. We in the business world could possibly be in the situation of being uninsured for the liability of a product that is "okay" for some uses and "hazardous" for others. How will we be protected from this type of claim? My understanding of the

Comprehensive Environmental Response and Liability Act indicates there would be no protection for end users such as our business should there be a suit brought. As we all know, this can translate into financial destruction for our business and our employees. Our bonding/insurance companies are not going to want to insure us against this type risk therefore, in effect, making the product unusable.

If we were simply making the argument that use of coal ash is financially a net positive for us it would not override the need to protect the citizens of this country. But that is not the sum total of our stance; coal ash has been reviewed many times in the past and determined not to be hazardous. As Governor Joe Manchin recently stated:

> "The safety of fly ash was evaluated in 2000 by the Clinton administration, which determined after an exhaustive analysis that coal ash should not be designated as a "hazardous" waste.
>
> In the 10 years since that decision, the EPA has calculated that ash recycling by the cement and concrete industry alone has reduced carbon emissions by 117 million tons. For comparison, all the SUVs on our country's roads emit about 70 million tons of carbon each year, according to the environmental group, Environmental Defense.
>
> This view is not uncommon. Every key federal agency that has weighed in on the issue — the departments of Energy, Interior, Agriculture and Transportation, the Small Business Administration, and the Army Corps of Engineers -- opposes regulating coal ash as hazardous waste."

The toxicity characteristics of fly ash do NOT qualify it as a hazardous waste. The characteristics of fly ash are similar to that of soils, stone, sand and other materials used in the production of

concrete, such as Portland cement. Various government agencies have supported this finding.

In summary, while it is understandable that the disaster in Tennessee causes a "second look" at insuring the safety of our environment that is not a reason to label a product as hazardous when there's no scientific data to support that. If there needs to be further safeguards for disposal of CCRs then surely those can be implemented without destroying a large segment of our economy. The use of coal ash has been beneficial to all end users and a hazardous label can very quickly end that. The costs to our economy and workforce would be catastrophic.

Thank you for this opportunity to testify on behalf of Bross Construction.

ACAA American Coal Ash Association

Advancing the management and use of coal combustion products.

November 17, 2009

The Honorable Lisa Jackson
Administrator
U.S. Environmental Protection Agency
Ariel Rios Building, Mail Code 1101A
1200 Pennsylvania Ave. N.W.
Washington, D.C. 20460

Mr. Alexander Cristofaro
Small Business Advocacy Chair
U.S. Environmental Protection Agency
1200 Pennsylvania Ave. N.W.
Mail Code: 1803A
Washington, DC 20460

RE: Request for SBAR Panel for Coal Combustion Residuals Rulemaking

Dear Administrator Jackson and Mr. Cristofaro,

We write on behalf of the American Coal Ash Association ("ACAA") to request that the U.S. Environmental Protection Agency ("EPA") immediately convene a Small Business Advocacy Review (SBAR) panel to assess the significant economic impacts that will be imposed upon small business beneficial use providers as a result of EPA's development of comprehensive federal regulations for coal combustion residuals ("CCRs"). As you know, EPA's Proposed Rule: Disposal of Coal Combustion Residuals From Electric Utilities is pending at the Office of Management and Budget ("OMB").

We are joining in and supporting the request of November 3, 2009 for a SBAR panel by the American Public Power Association (APPA) and the National Rural Electric Cooperative Association (NRECA). Like APPA and NRECA, ACAA has many members that are small businesses that would be adversely affected by the proposed rule.

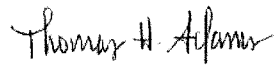
In this federal rulemaking of CCRs, ACAA understands that EPA's proposed draft rule would regulate the disposal of CCRs as hazardous waste under Subtitle C of the Resource Conservation and Recovery Act ("RCRA"). Regulating CCRs destined for disposal as hazardous waste will have a significant detrimental impact upon beneficial use and EPA must *not* assume that no economic impact will occur to the beneficial use industry. We believe that the potential economic impacts of such an approach on small businesses requires scrutiny which is not accounted for in the current draft rule. Since EPA concedes that CCRs disposal standards under either a Subtitle C or D approach will essentially be equivalent, the impacts to the beneficial use industry including numerous small businesses must be taken into account and should be the deciding factor to persuade EPA to choose Subtitle D of RCRA. ACAA seeks to work with EPA to address concerns and earnestly requests that the impacts be addressed prior to issuance of this rule.

EPA's obligation under the Small Business Regulatory Enforcement Fairness Act ("SBREFA") require it to give due consideration to alternative regulatory approaches that minimize impacts on small businesses. A Subtitle D approach will not lessen the protection to human, health and the environment but will allow for beneficial re-use of an important resource. We believe that EPA must convene a SBAR panel prior to issuance of this rule for these economic impacts to beneficial re-use to be properly considered.

Since 1966 the ACAA has represented those interested in promoting the use of coal combustion products in ways that benefit our environment, our economy, and our society. In the most recent survey of coal combustion product use it was reported that 44% of the coal combustion products generated in 2008 were used beneficially. As recently as 2000 the beneficial use rate was only 30%.

ACAA believes it is imperative for EPA to convene a SBAR panel to assess the significant economic impacts that will be imposed on small businesses as a result of EPA's development of comprehensive federal regulations for CCRs. We believe that this panel must be convened prior to publication of the proposed rule so that EPA complies with its obligations under SBREFA to properly assess the proposal's economic impacts on small businesses and minimize the burden of its regulations on small entities to the extent feasible, while still meeting applicable statutory obligations.

Very truly yours,



Thomas Adams
Executive Director
American Coal Ash Association

cc: Mathy Stanislaus, EPA
Mattew Hale, EPA
Cass Sunstein, OMB
Courtney Higgins, OMB
Keith Holman SBA
Diane Poster, CEQ

35 North Main Street
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Jasper, GA 30143
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January 13, 2010

Mr. Alexander Cristofaro
Small Business Advocacy Chair
Director, Office of Regulatory Policy & Management
U.S. Environmental Protection Agency
1200 Pennsylvania Ave., N.W.
Mail Code: 1803A

Re: Request for SBAR Panel for Coal Combustion Residuals Rulemaking

Dear Mr. Cristofaro:

I was recently informed that the American Coal Ash Association's request for a Small Business Advocacy Review Panel was not granted. As a small business owner, I write to explain why this decision has negative impacts on many small businesses.

Full Circle Solutions, Inc. is a small business with 43 employees. We have constructed geotechnical fills with coal combustion residuals (CCRs) in North Carolina and Virginia for over twenty years. We work primarily with Independent Power Producers and other smaller coal-fired industries that do not have large amounts of land available for basin or landfill disposal. Through our efforts, over 10 million tons of CCRs have been diverted away from municipal solid waste landfills into beneficial uses.

We provide a benefit to our industrial clients with a lower cost alternative to land filling their CCRs. We also provide benefits to the communities in which our structural fills have been constructed. The use of CCRs in geotechnical fills saves valuable landfill space, prevents the need for additional borrow pits and provides industrial and commercial property for economic development and job production. Most of the land upon which we build could not be used for economic development. The earthwork required to develop these properties would otherwise be cost-prohibitive.

Two examples of communities which have benefited from our work are the Town of South Boston and the City of Petersburg, both in Virginia. We partnered with the Town of South Boston to construct Houghton Industrial Park. The property designated by the town for their industrial park was mostly rolling hills which would require over 1.5 million cubic yards of earthwork. Estimates for this earthwork are over six million dollars. We were able to construct the building pads at almost no cost to the city. City officials say they doubt this would project would ever have been completed without our involvement and the use of CCRs. As a result, sixteen small businesses employing approximately one hundred and fifty people have located in this industrial park. The use of CCRs in geotechnical fills has benefited not only our small business, but also other small businesses that build their facilities on the property we develop.

In Petersburg, we recently completed the Peter's Pointe Business. Petersburg had no available property to attract new industries and create jobs. Using CCR's, we constructed an industrial park with approximately 150 acres that are now available for the city to use in its economic development plans. If the City of Petersburg had undertaken this project, earthwork alone would have cost over four million dollars an amount which would have been prohibitive for the city.

Development of CCR geotechnical projects is never an easy process. It normally takes careful communication and education of local and state regulatory agencies, elected officials, and the community in which the project is constructed. People who are unfamiliar with CCRs often ask questions such as "Isn't this sham recycling?"; "Aren't you going to pollute the groundwater?"; and "Isn't this stuff toxic?" To help answer these legitimate questions, we have always been able to point to the extensive amount of work done by EPA in the previous two Regulatory Determinations and to EPA's desire to promote the use of CCRs in environmentally safe manners through the C2P2 partnership. The determinations that CCRs are not hazardous waste have been extremely important to helping people understand that risks from CCR structural fills may be managed safely and responsibly.

In the past several months, reports that EPA is considering a hazardous waste classification have made development of our CCR projects extremely difficult. These reports have caused the uninitiated to believe that CCRs are in some manner like wastes which are highly toxic or radioactive. They fear the unknown and rarely trust those who are trying to develop the project. As a result, we have repeatedly been told by developers and local governing officials they do not want to be involved with what they consider a hazardous waste landfill.

Even if CCRs placed in geotechnical applications are given an exemption to hazardous waste regulations, they will be considered hazardous by local governments and citizens. This is already occurring. One example occurred in the past month. After working for over three years and spending nearly $200,000.00 to develop a project in eastern Virginia, the local government denied rezoning because they did not want a project which could be called a hazardous waste project. Although we demonstrated safety to human health and the environment and offered great economic benefits to the community, the project was not approved. The only reason given was that they were concerned about the hazardous label.

This project is not the only one we have lost in the past few months due to the hazardous waste issue. We have offered numerous communities and developers an opportunity to develop their projects at a cost well below what they would spend on traditional earthwork. When they hear CCRs are involved, the conversation often goes no further. Even the thought that EPA might call this material hazardous waste has already caused harm to the industry which will take years to overcome.

CCR geotechnical fills are not the only area where we have encountered difficulties due to the potential hazardous waste label. We supply bottom ash to a number of masonry block manufacturers. They have told us that if the hazardous label is placed on CCRs they will need to stop using the product. They are concerned that they will face spurious law suits even if beneficial use is exempted from hazardous waste regulation. The negative perception of a hazardous waste label has and will cause great damage to the beneficial use of this product.

In summary, we have already seen that any hazardous label given to CCRs will have unnecessary negative impacts to the beneficial use of this valuable product. We have seen these negative impacts affect our small business and can easily see the negative impacts that will occur to other small businesses and communities. Therefore, we request you to become fully involved in protecting small businesses from a rule that will certainly threaten their viability.

Sincerely,

Robert J. Waldrop
President & CEO

CC: Kevin Neyland, Cortney Higgins, Dominic Mancini OMB/OIRA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

RECEIVED
FEB 1 2 2010
FULL CIRCLE SOLUTIONS INC
WOODSTOCK, GA 30189

OFFICE OF
POLICY, ECONOMICS
AND INNOVATION

February 1, 2010

Mr. Robert J. Waldrop
President & CEO
Full Circle Solutions, Inc.
35 North Main Street, Suite A
Jasper, GA 30143

Dear Mr. Waldrop:

Thank you for your January 13th correspondence requesting a Small Business Advocacy Review Panel for EPA's Coal Combustion Residues rulemaking. EPA takes its statutory obligations under the Regulatory Flexibility Act very seriously. EPA appreciates hearing the concerns you have highlighted in your letter. We will fully consider your concerns as we move through the rulemaking process.

I thank you again for taking the time to relay your concerns. Please note that you also have the opportunity to provide input on this rule through the regular public comment period, which will commence at the time the proposed rule is published in the Federal Register. If you have further questions, please do not hesitate to contact my RFA staff lead, Lanelle Wiggins at 202-566-2372 or wiggins.lanelle@epa.gov.

Sincerely,

Alexander Cristofaro
Small Business Advocacy Chair
Director, Office of Regulatory Policy & Management
U.S. Environmental Protection Agency

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

AUG 13 2010

OFFICE OF CONGRESSIONAL AND
INTERGOVERNMENTAL RELATIONS

The Honorable Heath Shuler
Chairman
United States House of Representatives
Committee on Small Business
Subcommittee on Rural and Urban Entrepreneurship
Washington, D.C. 20515

Dear Chairman Shuler:

Thank you for your questions and the questions from other subcommittee members posed to the U.S. Environmental Protection Agency (EPA) during the July 22, 2010, Committee on Small Business, Subcommittee on Rural and Urban Entrepreneurship hearing title, "Coal Combustion Byproducts: Potential Impact of a Hazardous Waste Designation on Small Businesses in the Recycling Industry."

Please find enclosed responses to these questions. I hope this information will be useful to you and members of the Subcommittee. If you have further questions, please contact me or your staff may contact Amy Hayden in EPA's Office of Congressional and Intergovernmental Relations at (202) 564-0555.

Sincerely,

David G. McIntosh
Associate Administrator

Enclosure

cc: Ranking Member Blaine Luetkemeyer

Committee on Small Business
Subcommittee on Rural and Urban Entrepreneurship
U.S. Environmental Protection Agency Responses to Questions for the Record
July 22, 2010

Question from Chairman Shuler: Why hasn't EPA looked at all indirect costs? If CCR is considered a hazardous waste, won't that impact small businesses? Would EPA calculate the indirect impact to recyclers?

Answer: As stated in testimony provided by the U.S. Environmental Protection Agency (EPA), the Agency has not made a decision on whether to regulate the disposal of coal combustion residuals under subtitle C of the Resource Conservation and Recovery Act (RCRA). Rather, EPA has co-proposed two options. Under the first regulatory alternative, EPA would list these residuals, when destined for disposal in landfills and surface impoundments as a "special waste" subject to regulation under subtitle C of RCRA, which would create a comprehensive program of federally enforceable requirements. Under the second alternative, EPA would regulate the disposal of coal combustion residuals under subtitle D of RCRA by issuing national minimum criteria, which would be enforced through citizen suits or by the states. Under both alternatives, EPA is not proposing to change the 2000 Regulatory Determination for coal combustion residuals that are beneficially used and thus, these residuals would remain exempt from federal regulation.

EPA conducted two economic analyses in support of the proposed rule – one that looked broadly at the costs and benefits of the proposed rule (the regulatory impact analysis), and one that was focused on the direct impacts to small business (small business analysis). The regulatory impact analysis for the proposed rule examined both direct and significant indirect economic impacts of the proposed rule for both Subtitle D and Subtitle C options. The analysis estimated direct costs to the utilities, ancillary costs to the government, the benefits of ground water protection, the benefits of avoided structural failures of impoundments, the indirect effects on beneficial use, as well as the indirect effects on electricity prices. EPA also looked at the potential indirect impacts on beneficial use with respect to their aggregate benefits to society. The Agency analyzed three scenarios for the potential effect of RCRA regulation of CCR disposal under subtitle C on future CCR beneficial use. The scenarios analyzed were: an induced increase in beneficial use of CCRs; an induced decrease in beneficial use; and no impact on beneficial use. Under each of these three scenarios, EPA evaluated the resource consumption, pollution, and economic impacts.

As part of the small business analysis (see Attachment A), EPA analyzed the direct impact of the rule on entities subject to the requirements of the rule, i.e., coal-fired electric utility plants. EPA reached a conclusion that none of the proposed alternatives (including the Subtitle C option) would have a significant economic impact on small entities. EPA did not calculate the impacts on small recyclers of CCR, because under EPA's proposal, the Agency's 2000 Regulatory Determination would remain unchanged and the existing beneficial uses of CCR would remain exempt from RCRA regulation, and thus the regulation would not have a direct effect on such entities, nor would recyclers be subject to the requirements of the rule. Moreover, according to Section 2.5 of EPA's November 2006 guidance on the Regulatory Flexibility Act, EPA does not

usually evaluate (a) impacts on small entities which are not "subject to the requirements of the rule" and (b) impacts on small entities which are only indirectly affected by the rule. Nevertheless, as Deputy Assistant Administrator Lisa Feldt stated during the hearing, EPA welcomes the submission of any additional information or data on the impacts to individual recyclers or other entities, including small businesses, during the public comment period. EPA will consider such comments as it develops the final rule.

Question from Representative Bright and Representative Dahlkemper: If EPA estimates a 6% increase in utility rates as a result of the proposed rule, this concerns me. I would like more information about this. Did EPA consider the potential effect on industry of a C designation?

Answer: EPA did not estimate a "6% increase in utility rates." EPA estimated a potential increase of 0.172% under the Subtitle D option (i.e., 0.015 cents per kilowatt-hour) to 0.795% under the Subtitle C option (i.e., 0.070 cents per kilowatt-hour) in potential average electricity prices charged by coal-fired electric utility plants on a nationwide basis. EPA estimated the potential impact of the proposed rule on electricity prices assuming that 100% of the costs of the rule would be passed through to coal-fired electric utility customers,--that is, no electricity generation by nuclear, oil, natural gas, hydroelectric, etc, and that all 495 existing plants (as of 2005) would continue operation

Here are illustrative examples of potential monthly electricity cost increases ***on a nationwide basis*** for three types of customers (i.e., residential, commercial, and industrial) of coal-fired electric utility plants:
1. Residential: According to the Energy Information Agency, the average consumption for a U.S. residential utility customer in 2008 was 920 kilowatt-hours per month at a cost of $103.67 per month, suggesting a potential increase in the average residential monthly electric utility cost for customers of coal-fired electric utility plants of (920 kWh) x (0.07 cents per kWh) resulting in a potential increase of 64.4 cents per month.
2. Commercial: According to the Energy Information Agency, the average monthly electricity consumption and cost to a U.S. commercial customer in 2008 was 6,339 kilowatt-hours per month at a cost of $657.02 per month, suggesting a potential increase in the average monthly electric cost for commercial customers of coal-fired electric utility plants of (6,339 kWh) x (0.07 cents per kWh) resulting in a potential increase of $4.44 per month.
3. Industrial: According to the Energy Information Agency, the average monthly electricity consumption and cost to a U.S. industrial customer in 2008 was 108,567 kilowatt-hours per month at a cost of $7,413.54 per month, suggesting a potential increase in the average monthly electric cost for industrial customers of coal-fired electric utility plants of (108,567 kWh) x (0.07 cents per kWh) resulting in a potential increase of $76 per month.

In addition to calculating the potential average increase in electricity prices nationwide, EPA's electricity price analysis (see Attachment B) also looked at the potential effect in individual states (local markets). As stated by Deputy Assistant Administrator Lisa Feldt during the hearing, the potential statewide average electricity price increases ranged from 0.0% to 5.58% (or 0.00 to 0.49 cents per kilowatt-hour) under the Subtitle C option. On a state-by-state basis, potential increases in electricity prices charged by coal-fired electric utility plants could increase

from 0% (Connecticut, Massachusetts, New York) to 1.22% (Montana) under the Subtitle D option, and could increase from 0% (Washington) to 5.58% (Montana) under the Subtitle C option.

Thirty-four states are projected to experience less than a 1 ***percent*** increase in electricity rates, ***18 states and territories are projected to experience an increase of between 1 and 2 percent, while*** four states would have potential price increases greater than 2 percent under this analysis. In the case of Pennsylvania, EPA estimated that the potential price increase would be 0.702% under the Subtitle C option.

As noted above, the regulatory impact analysis for the proposed rule examined both direct and significant indirect economic impacts of the proposed rule for both Subtitle D and Subtitle C options.

Question from Representative Thompson: EPA estimates an increased electricity cost of approximately 6%. Does this include other realities such as cap and trade and other EPA regulations that could increase the cost of fossil fuels? Coal accounts for 60% of power in Pennsylvania.

Answer: As already noted, EPA did not estimate "an increased electricity cost of approximately 6%." EPA's electricity price analysis considered the potential economic impacts attributable to this rule. As stated above, EPA estimated the potential increase in average electricity prices charged by coal-fired electric utility plants on a nationwide basis could be 0.172% to 0.795%. On a state-by-state basis, the potential increases in electricity prices charged by coal-fired electric utility plants could increase from 0.0% to 5.582% in individual states. In the case of Pennsylvania, EPA estimated that the potential price increase would be 0.702% or 0.00063 cents per kwh under the Subtitle C option. EPA's analysis also did not consider the potential effect of possible future legislation or other EPA regulations if passed. However, EPA recognizes that major regulations have either been proposed (e.g., Transport Rule) or are in process of being proposed (e.g. Utility MACT and Section 316b of Clean Water Act). These regulations would have an impact on coal-fired electric utility plants. However, because EPA does not have complete impact estimates for these other rules, EPA restricted the price analysis for the CCR proposed rule to only the information that was generated for this RCRA proposed rule.

Question from Representative Dahlkemper: I am concerned that the C2P2 information has been taken down from the EPA website. I would like EPA to explain why they did this.

Answer: The Agency continues to support the beneficial use of coal combustion residuals. EPA is not proposing to change the 2000 Regulatory Determination for coal combustion residuals regarding beneficial use and thus, these residuals would remain exempt from RCRA regulation. The proposed rule did, however, discuss and seek comment on certain uses of coal combustion residuals, particularly when used in an unencapsulated form. Consequently, EPA decided to remove the C2P2 pages from the website for review to ensure they are consistent with the language in the proposed rule. Materials that were on the C2P2 website that are germane to the coal combustion residual rulemaking have been placed in the rulemaking docket and are available to the public.

7B. Small Business Impact Analysis (RFA/SBREFA)

According to the requirements of the 1980 Regulatory Flexibility Act (RFA) as amended by the 1996 Small Business Regulatory Enforcement Fairness Act (SBREFA), Federal regulatory agencies are required to make initial determinations if proposed regulatory actions may have a "significant economic impact on a substantial number of small entities" (SISNOSE). Small entities include small businesses, small organizations, and small governmental jurisdictions. Agencies are required to conduct a Regulatory Flexibility Screening Analysis (RFSA) to make this determination. This section of the RIA presents the methodology and findings for the RFSA conducted for the proposed rule.

Unless Agencies are able to certify that a particular regulatory action is not expected to have a SISNOSE, the RFA/SBREFA requires a formal analysis of the potential adverse economic impacts on small entities, completion of a Small Business Advocacy Review Panel (proposed rule stage), preparation of a Small Entity Compliance Guide (final rule stage), and Agency review of the rule within 10 years of promulgation.

The small business impact analysis of this RIA follows the four analytic steps described in EPA's RFA/SBREFA analysis guidance[172]:

Step 1: Determine which small entities are subject to the rule's requirements
Step 2: Select appropriate measures for determining economic impacts on these small entities and estimate those impacts
Step 3: Determine whether the rule may be certified as not having a significant impact on small entities (SISNOSE)
Step 4: Document the screening analysis and include the appropriate RFA statements in the preamble

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- **Step 1: Identification of Small Entities**

The scope of entities addressed by this analysis includes the affected coal-fired electric utility plants in NAICS code 221112. Not included in the scope of this RFA/SBREFA analysis are offsite commercial landfills which currently receive and dispose CCR generated by electric utility plants. EPA's RCRA statute does not provide EPA with authority to collect information from solid waste facilities; it only provides EPA with authority to collect information from RCRA-regulated hazardous waste management facilities (via the RCRA biennial report). EPA does not know the identity, company size, or other information about the offsite landfills currently used by the electric utility industry. Therefore, this RFA/SBREFA analysis is limited to only electric utility plants. Consistent with EPA's RFA/SBREFA guidance (page 15), this RIA applies the following small size definitions for owner entities of electric utility plants:

Small company: Based on the US Small Business size standard for NAICS code 221112 (fossil fuel electric utility plants): a company which generates less than 4 million megawatt-hours electricity output per year.

[172] EPA's RFA/SBREFA guidance: "EPA's Action Development Process: Final Guidance for EPA Rulewriters: Regulatory Flexibility Act as amended by the Small Business Regulatory Enforcement Fairness Act", EPA Office of Policy, Economics & Innovation, Nov 2006, 105 pages: http://www.epa.gov/sbrefa/documents/rfaguidance11-00-06.pdf

Small government: Based on the RFA/SBREFA's definition (5 US Code section 601(5)) of small government jurisdiction as the government of a city, county, town, township, village, school district, or special district with population <50,000.

Based on the nameplate megawatt (MW) capacity for all electricity generating units (including those powered by non-coal fuel types) at each electricity plant from the 2007 DOE-EIA 860 database, this RIA estimated annual megawatt-hours electricity generation capacity by multiplying the nameplate capacity by (a) 365 days per year, and (b) 24 hours per day to calculate each owner entity's annual electricity capacity. **Appendix D** of this RIA indicates the assigned size of the owner company or city government for each electric utility plant according to two size categories: "Small" or "Non-small".[173] **Exhibit 7B** below presents the resultant count and summary of the characteristics of the small electric utility entities as estimated in this RIA.

Exhibit 7B
Summary of Characteristics of Small Electric Utility Entities

	A	B	C	D	E (D / B)
Small Entity Sub-Categories	Count of coal-fired electric utility plants (2005/2007)	Estimated count of owner entities (2005/2007)	Estimated 2007 annual megawatt hours (mwh) capacity for all electricity plants owned by all entities	Estimated 2009 annual electricity sales for all entities ($millions/year)	2009 average annual electricity sales revenue per entity ($millions/year)
1. Small City Government	33	33	34.0	$2,592	$78.5
2. Small Company	12	11	10.6	$948	$86.2
3. Small Cooperative	6	6	12.0	$947	$157.8
4. Small County Government	1	1	0.3	$23	$23
Summary:					
All small entities =	**52 plants (11%)**	**51 entities (26%)**	**56.8 (1%)**	**$4,509 (1%)**	**$88.4**
All non-small entities =	443 plants (89%)	149 entities (74%)	5,380.5 (99%)	$419,056 (99%)	$2,812.5
All entities (non-small + small) =	495 plants	200 entities	5,437 million mwh*	$423,565**	$2,118

Notes:
* Annual electricity generation capacity based on all electric plants and types of electric generation units (e.g. coal-fired, oil-fired, hydropower, nuclear, wind, biomass, etc.) owned by these companies, not just coal-fired electricity generation capacity.
** $423.6 billion per year annual electricity sales estimated in this RIA is 73% of the $581.6 billion per year total revenues reported for NAICS code 22 (Utilities sector) in the 2007 Economic Census at: http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=D&-ds_name=EC0700A1&-_lang=en

[173] It should be noted that some of the companies identified as small using the SBA size standard for NAICS 22 and the utility code specification in the 2007 EIA 860 database to identify each corporate entity may be subsidiaries of a larger holding company (classified under a different NAICS) rather than a larger power company. In addition some of these power companies may have merged. For example, State Line is owned by Dominion Resources of Virginia, Northeastern Power is owned by Suez Energy North America, Inc. (SEGNA), Rio Bravo Poso and Rio Bravo Jasmin are owned by the North American Power Group, Ltd (NAPG), TES Filer City Station LP is owned by TONDU, Public Service Enterprise Group (PSEG) and Excelon are merged. This approach likely overstates the number of small entities.

- **Step 2: Measures for Determining Economic Impacts on Small Entities**

According to Exhibit 1 of EPA's 2006 RFA/SBREFA small business impact analytic guidance, there are the following suggested tests that may be used to determine if small entities may be significantly impacted by a proposed rule:

- Small business impact tests:
  - Sales test: Annualized compliance costs as a percentage of sales
  - Cash flow test: Debt-financed capital compliance costs relative to current cash flow
  - Profit test: Annualized compliance costs as a percentage of profits

- Small government impact tests:
  - Revenue test: Annualized compliance costs as a percentage of annual government revenues
  - Income test: Annualized compliance costs to household (per capita) as a percentage of median household (per capita) income

Based on annual electricity generation data for the small owner entities in the electric utility industry identified in **Appendix D** of this RIA, the annual sales/annual revenue test was used for this analysis. As itemized and estimated for each owner entity in the spreadsheets presented as **Appendix M** to this RIA, for each small entity EPA computed the respective sales revenue test percentages by the equation below:

(AEGC x 1,000) x (ASP) x (CU) = annual $sales or $revenues per small entity

Where:

AEGC = Annual electricity generation capacity per-entity in annual million megawatts (per-entity megawatt data is displayed in **Appendix D**). This estimate involved downloading the annual million megawatt capacity data for each of the 495 electricity plants from the DOE-EIA website (2007), and then multiplying the capacity data by two factors:
  - 365 operating days per year
  - 24 operating hours per day

ASP = February 2009 average statewide retail price to ultimate consumers for electricity (i.e., cents per kilowatt-hour) for the relevant state or states applicable to the location of electric plants owned by each company; electricity price reflects the composite price charged to residential, commercial, industry and transportation sectors[174]

CU = 86.8% electric utility industry capacity utilization from 1972-2008 average reported by the 15 May 2009 Federal Reserve Statistical Release G.17 "Industrial Production & Capacity Utilization" data for Utilities at: http://www.federalreserve.gov/releases/g17/Current/default.htm

[174] DOE's Energy Information Administration (EIA) publishes state-by-state average retail electricity prices for four end-user sectors (i.e., residential, commercial, industrial, transportation) and on a composite basis at: http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html

- **Step 3 & Step 4: Determine and document whether the proposed rule may be certified as having "No SISNOSE"**

EPA determined whether each regulatory option may have a "significant impact on a substantial number of small entities" (i.e., SISNOSE) which may become subject to the requirements of the proposed rule. This determination involved comparing the estimated regulatory compliance costs for each entity as displayed in **Appendix J** of this RIA and as summarized in **Exhibit 7C** below (small entity row items 6, 7, 8, 9), to the respective annual sales and revenues for each entity estimated in Step 2 above. Numerically, this comparison involved calculating the percentage of regulatory compliance costs relative to annual sales and revenues for each company for each of the regulatory options. Then compared the percentage results for each small entity to the following three impact thresholds defined in Table 2 of EPA's RFA/SBREFA analytic guidance. **Exhibit 7D** below displays the numerical results of this analysis and the suggested RFA/SBREFA impact interpretation according to the three thresholds.

<1% threshold:	Annualized regulatory costs may be less then 1% of annual sales or revenues for small entities
1% or more threshold:	Annualized regulatory costs may be 1% or more of annual sales or revenues for affected small entities
3% or more threshold:	Annualized regulatory costs may be 3% or more of annual sales or revenues for affected small entities

Exhibit 7C
Summary of Regulatory Cost Estimates According to Electric Utility Plant Owner Entity Size/Type Category
($millions in 2009 price level; average annual amortized @7% discount rate over 50-year period 2012 to 2061)

Size/Type of Entity*	Count of plants in category***	Subtitle C Hazardous waste	Subtitle D (version 1)	Subtitle C for impoundments Subtitle D for landfills
1. Non-Small City	27 plants	$46.9	$27.1	$43.9
2. Non-Small Company	372 plants	$1,897.2	$378.5	$1,821.2
3. Non-Small Coop	20 plants	$87.7	$34.6	$85.3
4. Non-Small Federal	11 plants	$183.2	$20.8	$181.0
5. Non-Small State**	13 plants	$41.6	$27.1	$39.8
6. Small City	33 plants	$2.8	$1.6	$2.5
7. Small Company	12 plants	$4.1	$1.9	$2.0
8. Small Coop	6 plants	$10.4	$0.3	$0.3
9. Small County	1 plant	$0.004	$0.004	$0.004
Total all 9 categories =	**495 plants*** **	**$2,274**	**$492**	**$2,176**

Notes:
* Size/Type classification methodology defined according to **Exhibit 3B** of this RIA.
** State government costs include costs to (a) state government electric utility plants regulatory costs, plus (b) state government RCRA-authorized programs for option implementation.
*** The total count of coal-fired electric utility plants is shown in the Exhibit; however, only a sub-total of 467 of the 495 may incur these regulatory costs because 28 plants solely supply their CCR for beneficial uses.

Exhibit 7D Estimated Impact of Regulatory Options on Small Entities (RFA/SBREFA Analysis Results) ($millions average annualized direct costs @7% discount rate over 50-year period 2012-2061)			
Cost as Percentage of Annual Electricity Revenues	Subtitle C Hazardous waste	Subtitle D (version 1)	Subtitle C for impoundments Subtitle D for landfills
A. Count of Small Entities:			
Annualized cost on small entities:*	$17.3	$3.8	$4.8
Less than 1%	46	50	50
1% or greater	5	1	1
3% or greater	0	0	0
B. % of Small Entities:			
Less than 1%	90%	98%	98%
1% or greater	10%	2%	2%
3% or greater	0%	0%	0%
C. SISNOSE Findings:			
Less than 1%	Presumed No SISNOSE	Presumed No SISNOSE	Presumed No SISNOSE
1% or greater	Presumed No SISNOSE	Presumed No SISNOSE	Presumed No SISNOSE
3% or greater	Presumed No SISNOSE	Presumed No SISNOSE	Presumed No SISNOSE
* Source: Costs for each option based on total cost for the four small entity categories displayed as rows 6 + 7 + 8 + 9 from **Exhibit 7C**.			

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- **Limitations of RFA/SBREFA Determination**

Not included in the RFA/SBREFA analysis of this RIA are **two factors** unique to the electric utility industry, which may reduce the small entity impacts relative to the estimates above in this RIA:

- Factor #1 of 2: According to the 2007 DOE-EIA database on electric utility plants, two-thirds of the coal-fired electricity generation units at electric utility plants owned by small entities can switch to at least one of six other fuels:
    1. Agricultural byproducts (database code = AB)
    2. Distillate fuel oil (DFO)
    3. Natural gas (NG)
    4. Petroleum coke (PC)
    5. Propane (PG)
    6. Wood & wood waste solids (WDS)

- Factor #2 of 2: The small business impact analysis in this RIA applies the full industry compliance cost to the revenue and sales tests. However, because consumer demand for electricity is (a) highly price-inelastic and (b) projected go grow by 30% by year 2025[175], electric utility plants may be expected to pass-thru much, if not all, of their regulatory costs (pending state government utility rate hike approval). The next section of this RIA evaluates the possibility of regulatory compliance cost pass-thru.

- **Compliance Cost Pass-Thru Analysis**

  - Ability to Raise Electricity Prices

Traditionally, the electric utility industry has functioned as a regulated monopoly, providing essential electrical services under an exclusive franchise in exchange for having rates closely regulated by State public utility commissions (PUCs; sometimes called PSC public service commissions) and the Federal Energy Regulatory Commission (FERC). The FERC regulates rates charged for sales of bulk power between utilities, even if they are in the same state. It also regulates the pricing and use of transmission for wheeling, and asset transfers, including mergers. In most states (California de-regulated electricity in 1998), the PUCs/PSCs set allowable rates upon application by the utility, with other affected parties allowed to present testimony. By law the utility must recover its cost of service, which includes "prudently" incurred expenses and a "fair" return on equity.[176]

Based on the electricity ratemaking process described by the Pennsylvania PUC[177]as a case example, when an electric utility company seeks a price increase (aka rate hike), it must file a request with the PUC showing the proposed new rates and effective date, and must prove that the increase is needed. The utility also must notify customers at least 60 days in advance. The notice must include the amount of the proposed rate increase, the proposed effective date, and how much more the ratepayer can expect to pay. Under the law, the utility is entitled to recovery of its reasonably incurred expenses and a fair return on its investment. The PUC evaluates each utility's request for a rate increase based on those criteria. During the investigation, hearings are held before an Administrative Law Judge (ALJ) at which the evidence in support of the rate increase is examined and expert witnesses testify. In addition, consumers are offered an opportunity to voice their opinions and give testimony. Briefs may be submitted by the formal parties. A recommendation to the PUC is made by the ALJ. Finally, the matter is brought before the Commissioners for a vote and final decision. Together with the 60-day notice period, the rate increase process takes about nine months. Recent (2008) examples of requested or PUC-approved electricity rate hikes are summarized in **Exhibit 7E** below:[178]

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[175] 30% additional electricity demand forecst for year 2025 relative to year 2005, from slide 17 of "Energy & Water: Emerging Issues and Trands" by Richard Kottenstette and Mike Hightower, Sandia National Laboratories, at: http://www.ct-si.org/Summit2007/spk/RKottenstette.pdf
[176] Source: "Electric Utility Regulation" by Robert J. Michaels in the Concise Encyclopedia of Economics at: http://www.econlib.org/library/Enc1/ElectricUtilityRegulation.html
[177] Source: Pennsylvania Public Utility Commission, "The PUC Ratemaking Process and the Role of Consumers", January 2008 at: http://www.puc.state.pa.us/general/consumer_ed/pdf/Ratemaking_Complaints.pdf
[178] Source: "Recent Examples of Rate Increases in Vertically Integrated States", The Compete Coalition, Washington DC, 05 November 2008 at: http://www.competecoalition.com/resources/recent-examples-rate-increases-vertically-integrated-states

Exhibit 7E Summary of 2008 US Electricity Price Hikes			
Item	State	Effective date	Requested or approved price hike
1	AL	Oct 2008	14.6%
2	CO	Feb 2008	28%
3	FL	July to Oct 2008	10 to 37% (8 companies)
4	KS	2008	15%
5	MO	Jan 2008	28%
6	NC	Sept 2008 to Jan 2009	10% to 17.7% (3 companies)
7	SC	July to Oct 2008	6% to 10% (4 companies)
8	TVA (7 states)	Oct 2008	20%
	Overall range =	Jan to Oct 2008	6% to 37%
	Average (20 electricity plant owner entities) =		**19%**

Some state governments have deregulated the electric utility industry, thereby allowing multiple electric suppliers, not just a monopoly electricity supplier, to compete and set their own retail prices in those state markets. As of 2003, 18 states have deregulated and six states may soon deregulate:[179]

- Deregulated states (18): AZ, CT, DE, DC, IL, ME, MD, MA, MI, NH, NJ, NY, OH, OR, PA, RI, TX, VA (11 of these states no longer have a price cap)
- May soon deregulate (6): AR, MT, NM, NV, OK, WV (note: CA deregulated in 1998 but has suspended)

While average prices rose 21% in regulated states from 2002 to 2006, prices increased 36% during that period in 11 of the 18 deregulated states where rate caps expired, suggesting greater pricing flexibility in deregulated states.[180]

- Inelastic Demand for Electricity

At the wholesale level, as a result of technological and regulatory barriers, the majority of electricity pricing plans do not allow end users to see and react to the actual market value of their electricity consumption/ conservation. Since end-users do not face the real-time market price in making their consumption decisions, there is little demand reaction to changes in real time wholesale electricity prices.[181] At the retail level, consumer demand for electricity has been largely inelastic. The lack of real time metering at the retail level means that consumers don't know

[179] Source: "Status of State Electric Industry Restructuring Activity as of February 2003", US Dept of Energy, Energy Information Administration at: http://www.eia.doe.gov/cneaf/electricity/chg_str/restructure.pdf
[180] Source: "Shocking Electricity Prices Follow Deregulation", USA Today, 10 Aug 2007 at: http://www.usatoday.com/money/industries/energy/2007-08-09-power-prices_n.htm
[181] Source: page 1 of "Demand Responsiveness in Electricity Markets", Ronald Lafferty et al., Office of Markets, Tariffs and Rates, 15 Jan 2001 at: http://www.naseo.org/committees/energyproduction/documents/demand_responsiveness_in_electricity_markets.pdf

how much they use or indeed how much electricity costs until after the fact. Thus consumers cannot react to high prices easily by cutting consumption.[182]

- Cost Pass-Thru Conclusion

Based on the above three cost pass-thru factors consisting of (a) 20 examples of recent (2008) PUC-regulated rate hikes which average almost 19% per company which far exceeds the 1% and 3% SISNOSE screening analysis thresholds defined by EPA's guidance, (b) 11 of the 18 deregulated states which have de-regulated the price of electricity, and (c) the fact that consumer demand for electricity has been relatively inelastic, this RIA concludes that it is likely that electric utility suppliers could pass-thru all, or nearly all, of the future average annual regulatory compliance costs for the CCR proposed rule such that a significant impact on small entities and non-small entities would not occur.

[182] Source: "Power Price Volatility and Risk Management: An Introduction", Anne Ku, Sept 2000 (this is the original, unedited article, later submitted to Global Energy Business magazine Sept/Oct 2000) at: http://www.analyticalq.com/energy/volatility/default.htm

Chapter 7
Supplemental Analyses Required by Congressional Statutes or White House Executive Orders

Note: The computations presented in this Chapter are based on the cost estimates for the October 2009 draft RIA regulatory options using the larger dry conversion cost estimate prior to its update in **Chapter 4**. Because the high-end cost of the October 2009 draft RIA regulatory options (i.e., for the Subtitle C "hazardous waste" option) is larger than the high-end cost for the 2010 options (i.e., for the Subtitle C "special waste" option), the effects estimated in this Chapter are proportionately over-estimated.

7A. Electricity Price Impact (Executive Order 13211)

The 2001 Executive Order 13211[168] "Actions Concerning Regulations that Significantly Affect Energy Supply, Distribution, or Use" requires Federal agencies to evaluate and prepare a statement on any potential adverse effects of economically-significant rulemakings on energy supply, distribution or use, including:

- Shortfall in energy supply
- Energy price increases
- Increased use of foreign energy supplies

The OMB's 13 July 2001 Memorandum M-01-27[169] guidance for implementing this Executive Order identifies nine numerical indicators (thresholds) of potential adverse energy effects, three of which are relevant for evaluation in this RIA:

- Increases in the cost of energy production in excess of 1%
- Increases in the cost of energy distribution in excess of 1%
- Other similarly adverse outcomes.

Because this RIA did not collect and analyze data on energy production cost or energy distribution cost, this RIA evaluated the potential impact of the CCR regulatory options on electricity prices relative to the 1% threshold of both indicators as an indicator of "other similarly adverse outcome". This RIA calculated the potential increase in statewide electricity prices that the industry compliance costs might induce under each CCR regulatory option. This calculation involved plant-by-plant annual revenue estimates and annualized compliance cost estimates, and respective statewide average electricity prices for the 495 electric utility plants, according to the following four steps.

[168] The 18 May 2001 EO-13211 is available at: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=2001_register&docid=fr22my01-133.pdf
[169] OMB's 13 July 2001 Memorandum M-01-27 is available at: http://www.whitehouse.gov/omb/memoranda_m01-27/

- Step 1: Downloaded the annual million megawatt capacity data for each of the 495 plants from the DOE-EIA website (2007), and estimated annual electricity output for each plant, by multiplying the capacity data by three factors:
  - 365 operating days per year
  - 24 operating hours per day
  - 86.8% capacity utilization per year[170]

- Step 2: Estimated the annual electricity sales revenue for each plant by multiplying the estimated annual electricity output sold by each plant (from Step 1), by the respective statewide average retail price (May 2009) of electricity for all sectors (i.e., residential, commercial, industrial, transportation) from DOE-EIA at http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html

- Step 3: Added the estimated incremental regulatory costs on a plant-by-plant basis, to the estimated annual electricity sales revenue for each plant, to obtain a hypothetical future annual revenue target, which represents a 100% cost pass-thru scenario. This simple scenario represents an upper-bound case of potential electricity price increase. Furthermore, if this 100% cost pass-thru is averaged over the entire electricity supply in each state, not just averaged over the 495 coal-fired electricity plants as done in this RIA, the potential percentage increase in electricity price would be less than this upper-bound case presented in this RIA.

- Step 4: Divided the hypothetical future annual revenue target by the estimated annual electricity output for each plant, to obtain a hypothetical future (higher) target price for each plant, which incorporates the added regulatory cost. Compared the higher target price to the current price to calculate the potential price increase on a percentage basis for each of the 495 plants.

Exhibit 7A below presents the findings of this energy price evaluation on a state-by-state basis. As displayed in the bottom row of **Exhibit 7A**, none of the options have an expected nationwide average energy price increase >1%. **Appendix L** presents the plant-by-plant calculation spreadsheet used for this electricity price impact analysis.

Exhibit 7A
State by State Breakout of Average Electricity Price Increases Per Option

Item	Number of Plants	State	May 2009 statewide average electricity price ($ per kilowatt hour)	**Subtitle C hazardous waste** Average Price Increase	**Subtitle D (version 1)** Average Price Increase	**C - impoundments D - landfills** Average Price Increase
Average annualized cost (from **Exhibit 4F**) =				**$2,274**	**$492**	**$2,176**
1	2	AK	$0.1518	1.30%	1.23%	1.25%
2	10	AL	$0.0856	1.43%	0.189%	1.419%

[170] Source: 86.8% capacity utilization is the 1972-2008 annual average published in the 15 May 2009 Federal Reserve Statistical Release G.17 "Industrial Production & Capacity Utilization" data for Utilities at http://www.federalreserve.gov/releases/g17/Current/default.htm

Exhibit 7A
State by State Breakout of Average Electricity Price Increases Per Option

Item	Number of Plants	State	May 2009 statewide average electricity price ($ per kilowatt hour)	**Subtitle C hazardous waste** Average Price Increase	**Subtitle D (version 1)** Average Price Increase	**C - impoundments D - landfills** Average Price Increase
3	3	AR	$0.0762	0.293%	0.225%	0.283%
4	6	AZ	$0.1002	1.141%	0.622%	1.113%
5	6	CA	$0.1337	0.717%	0.676%	0.687%
6	14	CO	$0.0797	0.121%	0.006%	0.017%
7	2	CT	$0.1712	0.074%	0.000%	0.000%
8	0	DC	$0.1337			
9	3	DE	$0.1236	0.156%	0.127%	0.129%
10	15	FL	$0.1136	0.131%	0.077%	0.113%
11	11	GA	$0.0859	1.160%	0.163%	1.152%
12	2	HI	$0.1892	0.245%	0.171%	0.174%
13	19	IA	$0.0710	0.548%	0.198%	0.537%
14	0	ID	$0.0602			
15	25	IL	$0.0924	0.531%	0.099%	0.488%
16	26	IN	$0.0766	1.387%	0.207%	1.348%
17	8	KS	$0.0822	0.545%	0.190%	0.532%
18	21	KY	$0.0640	2.307%	0.593%	2.237%
19	4	LA	$0.0748	0.464%	0.040%	0.462%
20	4	MA	$0.1534	0.027%	0.000%	0.000%
21	8	MD	$0.1316	0.080%	0.017%	0.037%
22	1	ME	$0.1222	0.520%	0.346%	0.352%
23	22	MI	$0.0986	0.459%	0.052%	0.455%
24	16	MN	$0.0804	2.013%	0.471%	1.993%
25	20	MO	$0.0757	0.817%	0.116%	0.798%
26	5	MS	$0.0893	0.197%	0.106%	0.193%
27	5	MT	$0.0720	5.582%	1.193%	5.531%
28	22	NC	$0.0839	1.122%	0.148%	1.102%
29	7	ND	$0.0698	0.994%	0.012%	0.982%
30	7	NE	$0.0705	0.223%	0.206%	0.210%
31	2	NH	$0.1544	0.055%	0.004%	0.004%
32	7	NJ	$0.1421	0.118%	0.045%	0.045%
33	3	NM	$0.0769	2.103%	0.407%	1.729%
34	2	NV	$0.0960	0.548%	0.518%	0.526%
35	13	NY	$0.1543	0.024%	0.000%	0.000%
36	26	OH	$0.0930	1.193%	0.132%	1.157%
37	6	OK	$0.0698	0.151%	0.050%	0.081%
38	1	OR	$0.0751	0.212%	0.200%	0.204%
39	34	PA	$0.0960	0.702%	0.229%	0.665%

Exhibit 7A State by State Breakout of Average Electricity Price Increases Per Option						
Item	Number of Plants	State	May 2009 statewide average electricity price ($ per kilowatt hour)	**Subtitle C hazardous waste** Average Price Increase	**Subtitle D (version 1)** Average Price Increase	**C - impoundments D - landfills** Average Price Increase
40	0	RI	$0.1343			
41	14	SC	$0.0826	0.394%	0.028%	0.384%
42	2	SD	$0.0742	0.098%	0.084%	0.086%
43	7	TN	$0.0860	0.517%	0.001%	0.504%
44	19	TX	$0.1019	0.292%	0.038%	0.256%
45	6	UT	$0.0690	0.602%	0.336%	0.588%
46	16	VA	$0.0916	0.688%	0.078%	0.629%
47	0	VT	$0.1282			
48	1	WA	$0.0684	0.000%	0.000%	0.000%
49	17	WI	$0.0918	0.082%	0.063%	0.078%
50	16	WV	$0.0668	1.441%	0.615%	1.379%
51	9	WY	$0.0602	1.396%	0.315%	1.351%
Summary:						
		Minimum =	$0.0602	0.0000%	0.0000%	0.0000%
		Maximum =	$0.1892	5.5822%	1.2259%	5.5313%
		Average =	$0.0985	0.7489%	0.2259%	0.7076%
		Median =	$0.0860	0.5205%	0.1316%	0.4876%
		Nationwide =	**$0.0884**	**0.795%**	**0.172%**	**0.761%**

Because this price analysis is based only on the 495 potentially affected coal-fired electric utility plants (with 333,500 megawatts nameplate capacity) rather than on all electric utility and independent electricity producer plants in each state using other fuels such as natural gas, nuclear, hydroelectric, etc. (with 678,200 megawatts nameplate capacity), these price effects are higher than would be if the regulatory costs were averaged over the entire electric utility and independent electricity producer supply (totaling 1,011,700 megawatts, not counting the 76,100 megawatts of combined heat and electricity producers).[171]

- **Electricity Impact Findings**

On a nationwide basis for all 495 plants, compared to the estimated average electricity price of $0.0884 per kilowatt-hour across the 495 plants, the 100% regulatory cost pass-thru scenario may increase prices for the 495 plants by **0.172% to 0.795%** across the regulatory options. None of the regulatory options exceed the 1% threshold of EO 13211, thus this RIA does not include a "Statement of Energy Effect" as would be required by Section 1 of EO 13211 if the price impact indicator as estimated in this RIA exceeded 1%.

[171] Source: 2007 megawatt nameplate capacity data from the Energy Information Administration "Table 2.3. Existing Capacity by Producer Type, 2007" at http://www.eia.doe.gov/cneaf/electricity/epa/epaxlfile2_3.pdf

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Honorable Representative Blaine Luetkemeyer
1118 Longworth HOB
Washington, DC 20515

Subj: Hearing – July 22, 2010
Coal Combustion By-products: Potential Impact of a Hazardous Waste Designation on Small Business in the Recycling Industry

Dear Representative Luetkemeyer,

Thank you for hearing testimony on EPA's proposed rules for fly ash and inviting me to speak. I was impressed by your questions of EPA's staff Lisa Feldt and believe you got to the heart of the matter regarding TVA's Kingston facility. As you perceptively noted, this was a failure of the containment embankment or dam.

I have received a list of eight questions you had for me. While time did not permit us to discuss them at the hearing, my response is attached. Time also does not permit a review of these responses by the appropriate technical committees of ACI and, therefore, they are not from the Institute. My written testimony was reviewed and approved by ACI and should be considered an official Institute statement.

We are going to survey about 60,000 people interested in concrete. We will be able to gauge the industry's response on beneficial use of fly ash in concrete to EPA's Subtitle C approach to disposal. We will share the results with you and EPA when available.

The Institute and I are available to provide you and the Committee with technical information about using fly ash in concrete as you continue to consider EPA's proposed rule. Thank you again for including me and the Institute in this important process.

Very truly yours,

Richard D. Stehly

Richard D. Stehly, P.E., FACI
Principal

Attachment: Draft Stigma Survey (subject to revision)
Responses to Questions
September 2005 – Concrete International

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HOUSE COMMITTEE ON SMALL BUSINESS
HEARING – JULY 22, 2010
Coal Combustion By-products: Potential Impact of a Hazardous Waste Designation on Small Business in the Recycling Industry

Responses to Questions from Representative Luetkemeyer for Mr. Stehly

1. If EPA had been realistic about the potential consequences of designating fly ash as hazardous, should the Agency have examined the environmental costs of substituting Portland cement for fly ash in making concrete?

Response
In evaluating a Subtitle C approach to fly ash the EPA should consider all the potential consequences such as:

A. Increased use of portland cement caused by a reduction in fly ash use
B. Increased cost of concrete caused by an increased use of portland cement or other modifications necessitated by a reduction in fly ash use
C. Increased CO_2 emissions caused by an increase of portland cement use from a reduction in fly ash use
D. Increased cost of concrete for the mitigation of alkali silica reaction as a result of using expensive mitigation alternatives
E. Increased cost of nations infrastructure due to reduced service life and increased maintenance from a reduction in fly ash use
F. Need for increased landfill volumes

I have not reviewed the EPA's econometric model, nor the inputs they used in computing the impact of their proposed rules and offer no comments on the results.

2. Had EPA made a realistic assessment of the true environmental costs associated with eliminating fly ash from concrete, is it your opinion that the Agency's benefit-cost analysis would have generated a different benefit-cost ratio?

Response
I have not reviewed the EPA's cost benefit analysis in detail and offer no comments on their results.

3. Does fly ash replace Portland cement on an equal basis, i.e., if you remove one pound of Portland cement you can substitute it with one pound of fly ash?

Response
Fly ash is often used to replace portland cement on a pound for pound basis. Some State's Departments of Transportation require a greater substitution of fly ash for portland cement. ACI 232.2R-03 Use of Fly Ash in Concrete contains more information and is appended to my written testimony.

4. If fly ash is an effective substitute for Portland cement, is it possible to eliminate Portland cement as a product in concrete?

Response
Making concrete does not require portland cement and ACI's definition of concrete in ACI 116R-00 Cement and Concrete Terminology does not include the words portland cement, "a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate, usually a combination of fine aggregate and coarse aggregate." The vast majority of concrete does contain portland cement as it is a reliable, economical binder that is well understood. Other activators can be used to cause fly ash to form a binder. Vitruvious nearly 2,000 years ago used lime as the activator for volcanic ash in concrete in Roman construction. Similarly, lime can activate fly ash. More detail is contained in the ACI 232.2R-03 document.

For conventional structural concrete, that is concrete designed to carry an imposed load, fly ash contents are typically in the range of 15 to 35 percent by mass of the cementitious materials (ACI 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete) depending on the specific desired properties of the fresh and hardened concrete. Higher use of fly ash is possible. In the ACI document on fly ash (ACI 232.2) Section 6.6 specifically addresses high-volume fly ash concrete where more than 50% of the cementitious material is fly ash. In a peer reviewed paper appearing in the September 2005 volume of *Concrete International* the authors describe concrete made with 100% fly ash used for precast wall panels for the U.S. Forest Service. A copy is attached. As shown in this paper, concrete can be made using only fly ash, but this is not at all common. In other concrete products, such as controlled low-strength material, fly ash use levels are typically higher than in conventional structural concrete.

5. How does fly ash enable the use of marginal quality sand or gravel in concrete?

Response
Marginal quality sand and gravel can contain reactive forms of silica. Sodium and potassium alkalis in the portland cement can undergo "alkali silica reaction" (ASR), resulting in expansion and cracking of concrete. In the extreme case, the useful life of the concrete will be shortened. Some sources of fly ash are powerful mitigators of ASR. Fly ash usually costs much less than portland cement. Therefore, fly ash may provide an inexpensive method of allowing marginal aggregates to be used in concrete. More information can be found in document ACI 201.2R-08 Guide to Durable Concrete and in ACI 221.1R-98 Report on Alkali Aggregate Reactivity.

Also, fly ash permits us to reliably and economically build concrete structures in the southwest US that are exposed to a high concentration of sulfates in the soil, concrete structures exposed to marine environments and infrastructure that is exposed to vast amounts of deicing salts.

6. Does Concrete made with fly ash last longer than concrete without fly ash?

Response
Fly ash can extend the longevity of concrete. Concrete with fly ash will generally be less permeable which inhibits the ingress of water, deicers, sulfates and seawater. Many forms of concrete deterioration are from penetration of these agents. Reduced penetration extends useful life.

7. If so, should not Congress, as it considers a highway reauthorization bill, mandate the use of fly ash in concrete to the extent feasible given the engineering of a particular project?

Response
Most States' DOT and Federal agencies recognize the positive impact fly ash can have on concrete. The Comprehensive Purchasing Guideline has encouraged the use of fly ash in concrete purchased by the government for more than 25 years (see 40CFR Part 249, Section 6002 of RCRA).

The American Concrete Institute does not advocate the use of any particular material in making concrete. The Institute simply provides the knowledge on how to use a material properly. In practice, the selection of the concrete materials is the responsibility of the design engineer based on the needs of their design.

8. Are there any studies showing how much longer fly-ash based concrete lasts over other types of concrete?

Response

Increasing the durability and longevity of concrete can be accomplished by a number of different means and methods. Some of these are related to how concrete is placed, compacted, and cured, while others are related to how concrete is proportioned and what constituent materials are used in the concrete. Fly ash has been long recognized as a technically sound and economical means of improving the durability and longevity of concrete. ACI document 201.2R-08 Guide to Durable Concrete documents the various ways in which fly ash enhances the durability of concrete. These include resistance to alkali-silica reactivity, improved resistance of embedded steel to corrosion, resistance to chemical attack, and increased resistance to abrasion. Many project specific studies have been conducted to document the durability of fly ash concrete. The following example, based on the service life prediction guidance provided in ACI 365.1R-00 Service Life Prediction, demonstrates the effectiveness of fly ash added to concrete. The computer program Life-365 estimates an increase of the service life for a parking garage in Washington DC from 12 years to 15-1/2 years due to a 25% replacement of portland cement with fly ash.

To: ACI members and customers
(Also available to industry via link/button on flyash.concrete.org)

From: Ron G. Burg, ACI Executive Vice President <news@concrete.org>

Date: August 1, 2010

Subject: EPA's Proposed Rules for Regulation of Fly Ash and Other Coal Combustion Residuals

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On June 21, 2010, the U.S. Environmental Protection Agency (EPA) published a proposal to regulate coal combustion residuals (CCRs), including fly ash, under the Resource Conservation and Recovery Act (RCRA). Various portions of the RCRA allow EPA to regulate hazardous wastes (Subtitle C) as well as non-hazardous solid waste (Subtitle D). CCRs came to national attention in late 2008, when an impoundment holding disposed waste ash failed in Tennessee. The EPA's proposed regulations would lead to stronger oversight of CCR impoundments, along with measures to prevent environmental damage and contamination of drinking water.

In preparation for one final ruling, the EPA proposal calls for public comment on two options. The first lists CCRs that are destined for disposal as a "Special Waste" that is subject to Subtitle C of the RCRA, and creates a comprehensive program of federally enforceable requirements for management and disposal. The second would allow all CCRs to maintain the current exemption from Subtitle C requirements and instead use EPA's Subtitle D to set performance standards for waste management facilities, and would be enforced primarily through citizen suits. Under both options, EPA would establish requirements for liners in CCR storage facilities, require ground water monitoring, and leave in place the Bevill exemption for beneficial uses of CCRs, in which CCRs are recycled as components of products (including concrete) instead of placed in impoundments or landfills.

ACI is surveying its membership and will provide input to the EPA. Additional details of the two options are included on the subsequent survey pages. Please click on the link below to take the survey and submit your feedback to ACI. If you would like to comment directly to the EPA, ACI has provided technical resources and appropriate EPA links on flyash.concrete.org.

<<Link here>>

1. Please provide the following (optional):
   - Name
   - E-mail

2. Please identify your residency:
   - ☐ United States; including Puerto Rico, the Virgin Islands, Guam, and the Northern Mariana Islands
   - ☐ Outside of the United States

3. Please identify your ACI membership status:
   - ☐ Current
   - ☐ Past
   - ☐ Never been a member

4. Please identify your role in the concrete industry: (Select the one that is most appropriate)
   - ☐ Producer
   - ☐ Contractor
   - ☐ Architect/Engineer
   - ☐ Manufacturer/Material Supplier
   - ☐ Owner
   - ☐ Generator of CCRs (coal combustion residuals)
   - ☐ Other

5. Since CCRs came to greater attention following the impoundment failure at the Tennessee Valley Authority's plant in Kingston, Tennessee, in December 2008, how has your use/specification of fly ash been affected? (Please select only one)
   - ☐ Increased
   - ☐ No change
   - ☐ Decreased
   - ☐ Ceased

6. If your use/specification decreased or ceased since the impoundment failure, please indicate why:
   - Open-ended response

7. BACKGROUND: Adopted in 1980, Subtitle C of the Resource Conservation and Recovery Act established a federal program to manage hazardous wastes from cradle to grave, ensuring that hazardous waste is handled in a manner that protects human health and the environment. By using the Subtitle C option, the EPA would label CCRs as a "Special Waste," require the development of state or federal permit programs, allow for direct federal enforcement, and include related storage, manifest, transport, and disposal requirements and mechanisms for corrective action and financial responsibility.

   If the EPA establishes a rule listing CCRs that are destined for disposal as a Special Waste subject to Subtitle C, how would your use/specification of fly ash in concrete be affected? (Please select only one)

- ☐ Increase
- ☐ No change
- ☐ Decrease
- ☐ Cease
- ☐ Unsure

8. BACKGROUND: Subtitle D of the Resource Conservation and Recovery Act focuses on state and local governments as the primary planning, regulating, and implementing entities for the management of non-hazardous solid waste, such as household garbage and non-hazardous industrial solid waste.The Subtitle D option would go into effect sooner than a Subtitle C rule, with implementation required approximately six months after promulgation. However, the Subtitle D option would not require permit programs to be established, although states can establish such permit programs under their own authorities. The federal Subtitle D proposal would not be federally enforceable, although citizen's suits could be filed; and it would not establish the same extensive management requirements as Subtitle C for CCRs destined for disposal.

   If the EPA establishes a rule using the proposed Subtitle D option, how would your use/specification of fly ash in concrete be affected? (Please select only one)
   - ☐ Increase
   - ☐ No change
   - ☐ Decrease
   - ☐ Cease
   - ☐ Unsure

9. Considering potential action by the EPA, please provide any additional impact(s) regarding use of fly ash in your concrete:
   - Open-ended response

Thank you page:
Thank you for submitting information to ACI; your submittal will be combined with the responses of others and shared with the EPA in summary form. If you would like to comment directly to the EPA, ACI has provided technical resources and appropriate EPA links at flyash.concrete.org.

Field Trials of 100% Fly Ash Concrete

Charging, mixing, and placing procedures are verified

BY DOUG CROSS, JERRY STEPHENS, AND JASON VOLLMER

Research conducted at Montana State University has demonstrated that locally available, high calcium fly ash can be used as the sole binder in structural grade concrete. In our initial studies, we produced small trial mixtures that had strength and workability properties similar to those obtained with portland cement-based mixtures.[1,2] As a further demonstration of the potential application of this material, we have recently used ready mixed concrete equipment to produce fly ash concrete on a larger scale. Our trials have shown that the raw materials can be easily charged into a mixer, mixed thoroughly, discharged, transported, placed, and finished.

FLY ASH CONCRETE PRIMER

Although fly ash concrete and portland cement concrete have similarities, fly ash concrete requires particular care during the mixing process:

- To prevent flash set, a retarder (borax) must be mixed into the batch water;
- Because setting time can be dramatically reduced and strength can be seriously compromised if extra water is added, the correct amount of water must be provided at the outset; and
- Finally, because fly ash concrete is extremely sensitive to the order of combining the ingredients, the charging sequence must be well ordered and controlled.

FIRST FIELD TRIAL

In the summer of 2002, our first field trial using 100% fly ash concrete was conducted at a ready mixed concrete plant in Billings, MT. The focus of the trial was to verify that 100% fly ash concrete could be mixed in a large batch, using conventional equipment, and would have the workability, setting time, and strength typical of conventional concrete.

The mixture proportions for this trial were based on our previous laboratory work and comprised 40% paste and 60% aggregate. To obtain adequate workability and time to place the freshly mixed concrete, we selected a target slump of 100 to 150 mm (4 to 6 in.) and a minimum setting time of 3 hours. Because we were hoping to obtain a concrete that could be used in general applications, we also selected a target minimum compressive strength of 27.6 MPa (4000 psi) at 28 days.

For our binder, we selected a high calcium, Class C fly ash conforming to ASTM C 618,[3] produced by the J.E. Corette Power Plant in Billings, MT. Fly ash properties are shown in Table 1. We selected fine and coarse aggregates conforming to ASTM C 33[4]; our coarse aggregate had a nominal maximum size of 19 mm (3/4 in.). Mixture proportions are shown in Table 2.

When we selected the mixture proportions, we gave careful consideration to three parameters: water-

TABLE 1:
Chemical and physical properties of Corette Fly Ash

Chemical properties	%
Silicon dioxide	32
Aluminum oxide	17
Iron oxide	6
Sulfur trioxide	2
Calcium oxide	30
Moisture content	0
Loss on ignition	0.2
Physical properties	
Fineness, retained on No. 325 sieve, %	13
Strength activity index	
Ratio to control @ 7 days, %	82
Ratio to control @ 28 days, %	92
Water requirement, % of control	94
Soundness, autoclave expansion, %	0.04
Specific gravity	2.72

TABLE 2:
Mixture proportions for field trials 1, 2, and 3

Material	Field Trial 1, kg/m³ (lb/yd³)	Field Trial 2, kg/m³ (lb/yd³)	Field Trial 3, kg/m³ (lb/yd³)
Class C fly ash	500 (840)	582 (980)	500 (840)
Coarse aggregate	825 (1390)	722 (1220)	825 (1390)
Fine aggregate	413 (695)	413 (695)	413 (695)
Water	120 (200)	128 (215)	120 (200)
Borax	7.0 (11.8)	5.2 (8.8)	6.3 (10.6)

cementitious material ratio (*w/cm*), retarder type and amount, and mixing sequence. In fly ash-based concrete, these three parameters have equal importance, as even small variations in one or more can have dramatic and often detrimental effects on overall performance of the mixture.

Our existing laboratory data indicated that a mixture with a *w/cm* = 0.24 would have a slump between 150 and 225 mm (6 and 9 in.) and a 28-day, unconfined compressive strength in excess of 27.6 MPa (4000 psi).

To avoid flash set, we used borax as a retarding admixture. Our laboratory trials provided data that indicated that the amount of borax to obtain a given working time was a function of both the amount of fly ash and the amount water in the mixture. In this case, the appropriate amount of borax needed to provide about 4 hours of working time was 1.4% of the fly ash by weight.

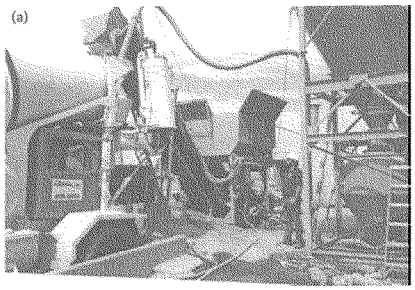
Although our laboratory trials indicated that setting times ranging between 0.5 and 8 hours could be achieved with an accuracy of 15 minutes or less, they also showed that this was possible only if the level of reactivity of the specific ash was known. We therefore developed procedures for establishing the setting time as a function of the amount of borax, fly ash, and water used in the mixture. These procedures required the preparation of only two bench-top batches of concrete comprising samples of the specific fly ash to be used in the field.

Our laboratory trials also indicated that the charging sequence for fly ash concrete is critical. Small variations in the quantities or the order in which components are combined can have significant and sometimes irreversible effects. Our procedures for preparing our field trials were as follows:

1) 85% of the mixing water, 100% of the retarding admixture (borax), and 20% of the coarse aggregate were charged into the spinning drum of the truck mixer.
2) After these ingredients had mixed for a minimum of 10 minutes, the remainder of the coarse aggregate, 100% of the fine aggregate, and 100% of the fly ash were simultaneously charged into the spinning drum. (The concrete plant used for the trials is well configured to charge all the material into the truck with minimal delay.)
3) The remaining 15% of the mixing water was used to wash any material that had collected in the funnel into the drum, and the concrete was mixed for at least another 10 minutes.

Following the procedures outlined, 2.3 m³ (3 yd³) of structural grade fly ash-based concrete was successfully batched in a ready mixed concrete truck. The concrete was used to cast small reinforced structural elements, compression test cylinders, and landscape blocks (Fig. 1).

Although a malfunctioning water meter created some doubt about the actual amount of water used in the first field trial, we believe that the total amount of water was relatively close to the design requirements, as the slump and early compressive strength obtained for this batch were comparable to those for our laboratory batches. The slump was measured at 215 mm (8.5 in.) and the 2- and 7-day compressive strengths were 20.0 and 22.7 MPa (2900 and 3300 psi), respectively. The 28-day compressive



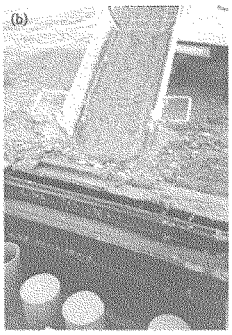


Fig. 1: Mixing and casting operations for Trial 1. This and other mixtures resulted in finished concrete with a consistent light brown color, directly reflecting the color of the fly ash used as the binder: (a) charging the truck mixer with the fly ash; and (b) casting landscape block

strength was 33.1 MPa (4800 psi), and the 1-year compressive strength was 55.2 MPa (8000 psi).

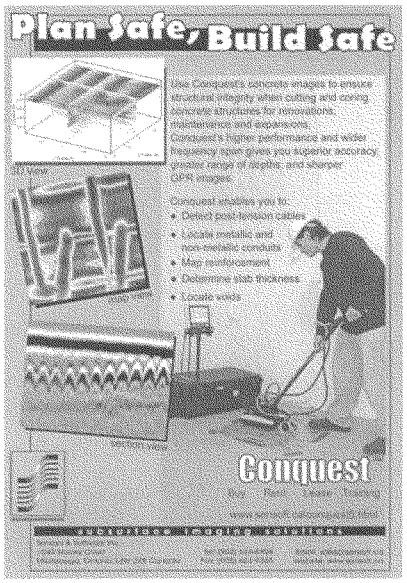
SECOND FIELD TRIAL

In the second field trial, we used 100% fly ash concrete to construct reinforced precast wall panels. The panels were fabricated using equipment common in the precast industry and were used as components in two vault toilet systems for the U.S. Forest Service. The systems are now located at a river access point along the Snake River outside of Jackson, WY.

Because the second field trial was conducted in an operating precast plant, we had to be careful not to disrupt the plant's production schedule. This placed additional constraints on the mixture proportions. The concrete was required to have a slump greater than 100 mm (4 in.), a setting time of 1 to 2 hours, and an 18-hour unconfined compressive strength of at least 19 MPa (2800 psi) (so that the panels could be stripped from their forms and handled the following morning). We were very fortunate, as the plant's managers allowed us to conduct several trial mixtures before actually casting the final product.

Six trial batches were prepared in the plant to develop a mixture that met these criteria. The mixing equipment, a stationary high-energy pan mixer, was significantly different from the mixer used in the first trial and from the equipment we used in the laboratory. Although we feared that the intensity of the mixing action would decrease the workability and setting time of the concrete, we observed negligible effects on the mixture performance. We also were concerned that, not only would we be unable to get the retarder adequately into the solution using this mixer, but that some retarder solution would be lost out of the discharge door of the mixing tub. These possible problems were minimized, however, by adding the water and borax to the mixer after the coarse and fine aggregate had been loaded into the mixing tub.

The final mixture proportions (shown in Table 2) for this trial consisted of 45% paste, 35% coarse aggregate, and 20% fine aggregate. The paste volume was 5% higher than in the first field trial to ensure that the detail from



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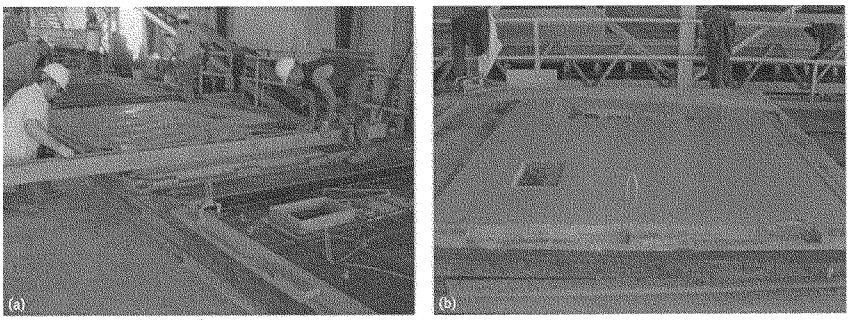

Fig. 2: Fabrication of precast wall panels. Workers remarked that the material was readily placed and finished: (a) workers screeding a wall panel; and (b) completed panel

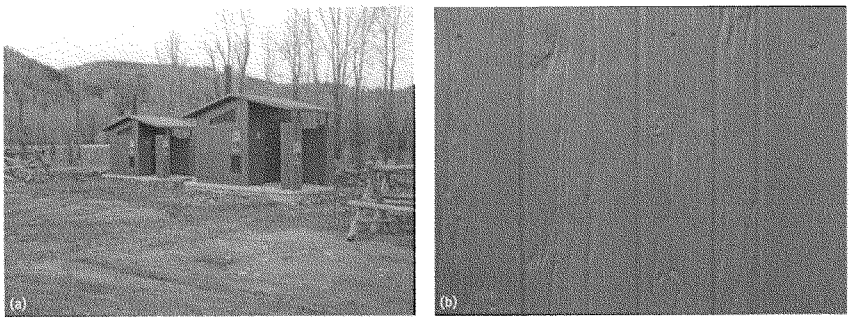

Fig. 3: Completed vault toilets: (a) overall view of installation; and (b) detail of finished wall surface

a wood grain form liner would be picked up in the finish on the precast panels. Three 1.2 m^3 (1.5 yd^3) batches of concrete were produced using this mixture proportion. The concrete had good workability, with an average slump of 127 mm (5 in.) and an average setting time of 2 hours. Workers were able to finish the panels using standard procedures (Fig. 2), and the installed panels had the desired appearance (Fig. 3). The 18-hour strength was 19 MPa (2790 psi) and the 90-day strength was 32 MPa (4577 psi).

THIRD FIELD TRIAL

In the third field trial, we again used typical ready mixed concrete equipment to mix 100% fly ash concrete for the footings and stem walls for a "green building" being constructed by homeWORD (a non-profit affordable housing developer in Missoula, MT). The mixture proportions (see Table 1) and mixing procedures were very similar to those used in the first field trial. In this trial, however, the material had to be transported 50 miles (80 km) to the job site after it was batched (a 1-1/2 hour trip). A total of 23 m^3 (30 yd^3) of concrete were batched in approximately three equal loads. The material, with a slump of approximately 180 mm (7 in.), was placed with a conveyor directly into the forms (Fig. 4). The setting time was approximately 4 hours. The 18-hour and 7-day compressive strengths were 21 and 31 MPa (3000 and 4500 psi), respectively.

FURTHER RESEARCH

While these first field trials were successful, we intend to futher investigate many of the material's properties.

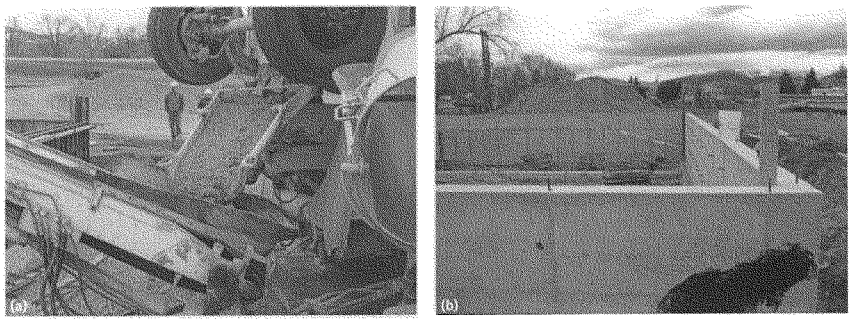

Fig. 4: Construction of building foundation. Three loads were successfully transported 50 miles (80 km) to the job site: (a) discharging concrete to conveyor; and (b) completed foundation

Our future work will focus on long-term durability and stability, notably with respect to freezing-and-thawing damage, sulfate attack, and surface abrasion. Further, we will continue to investigate fundamental methods for selecting mixture proportions.

Acknowledgments

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Received and reviewed under Institute publication policies.

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Honorable Representative Heath Shuler
422 Cannon House Office Building
Washington, DC 20515

Subj: Hearing – July 22, 2010
Coal Combustion By-products: Potential Impact of a Hazardous Waste Designation on Small Business in the Recycling Industry

Dear Representative Shuler,

Thank you for calling a hearing on this important topic and requesting my testimony. I understand you wanted to ask, "Will the Institute remove fly ash from 318 Building Code Requirements for Structural Concrete if EPA adopts a rule which lists fly ash for disposal as a special waste under RCRA Subtitle C Hazardous Waste Regulation." Should such a rule be adopted, the Institute will review all documents containing reference to fly ash. As a consensus Standards Developing Organization, each technical committee will review the documents under their jurisdiction and come to a conclusion about the inclusion, modification, or elimination of content about fly ash. I am aware that a proposal to remove fly ash from the code will be brought before Committee 318. The outcome of this proposal is uncertain.

The Institute is preparing to survey about 60,000 people who are interested in concrete. The survey will allow us to gauge the likely impact on beneficial use of fly ash in concrete, should the Subtitle C approach be selected by EPA. We will share the results with you and EPA when available.

The Institute and I are available to provide technical assistance to you and your Committee as you endeavor to find that middle ground around which a compromise can coalesce. Thank you again for including me and the Institute in this important process.

Very truly yours,

Richard D. Stehly

Richard D. Stehly, P.E., FACI
Principal

Attachment: Draft Stigma Survey (subject to revision)

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Hearing of the House Committee on Small Business,
Subcommittee on Rural Development, Entrepreneurship and Trade
"Coal Combustion Byproducts: Potential Impact of a Hazardous Waste Designation on Small Businesses in the Recycling Industry"
July 22, 2010

Statement of Jerry Liner, Carolina Stalite and Johnson Concrete

My name is Jerry Liner, and I represent several North Carolina businesses, including Carolina Stalite and Johnson Concrete, with concerns about the United States Environmental Protection Agency's (EPA) potential to treat bottom ash and fly ash the same when reused, when only fly ash reuse in concrete should be promoted. We believe that, when dumped, all types of coal ash should be treated the same and all be stringently regulated under Subtitle C to protect communities from harm. We believe that a Subtitle C "Special Waste" regulation would not put a stigma on recycling, and we will continue to reuse fly ash in our concrete products if EPA selects this regulatory option.

However, we want to note that when reused, different types of coal ash lead to differing results in a final product, and they should not be treated the same. Currently both options in EPA's co-proposal would exempt all beneficial uses from regulation, without distinguishing clearly among different types of coal ash.

Our company has been active in an attempt to educate construction professionals and public about the coal ash materials that can be reused in concrete and similar applications, and more importantly the difference in the two types of materials in terms of quality of the final product and potential dangers the final products may pose to consumers.

We have a great concern as to the decisions and rules that maybe implemented by EPA for these materials. The documents written by the EPA regarding coal combustion waste materials often refer to coal ash as one material. The fact is that coal combustion waste consists of four types of waste materials. We are concerned with EPA's potential to not distinguish between two particular types of coal ash, namely fly ash and bottom ash. The reuse of ***fly*** ash has been approved and regulated by the American Society for Testing and Materials (ASTM) in cement-based products such as concrete in ASTM C618-08a, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, and related ASTM provisions. ***Bottom*** ash, on the other hand, has not been similarly approved for use in concrete products by ASTM or any other agency, and should be the focus of the concern when considering new and better regulations. ***Fly*** ash alone is a byproduct that carries ASTM standards and has been used in the manufacturing and construction industry successfully, and should continue to be used as recycled waste material in pozzolanic materials.

The common use of fly ash in cement is requires replacement of only approximately ten percent of the cement in the material mix design. On the other, hand bottom ash waste material is used approximately at 65 percent of the total weight of the mix designs, making for a structurally weaker product that we belive may be more likely to release the hazardous components of coal ash that are reported by EPA. While fly ash is contained in the cement paste and bottom ash is *not contained* when used to manufacture concrete block, leaving the waste material exposed for leaching of the contaminants.

The direction we would like to propose would encourage only safe recycling of coal ash while discouraging unsafe dumping and unsafe reuse of coal ash:

1. Continue to exempt reuses of fly ash that have been approved by ASTM standards.
2. Regulate the transportation of fly ash in container trucks and rail cars and other enclosed forms of transportation. We recognize that legally EPA can only regulate transportation of fly ash if the disposal of coal ash is regulated under Subtitle C of RCRA, because Subtitle D of RCRA would not allow EPA to regulate transportation of coal ash at all.
3. Disallow the use of the bottom ash material in any type of manufactured cement products including concrete block.
4. Regulate coal ash disposal pits designed by EPA for containment in order to protect groundwater. The material used as structural fill should be with similar regulation set forth for disposal sites, as EPA has decided to do in both proposals.

It is our hope that this committee can express to EPA our concerns for strict nonuse of bottom ash with the continued ASTM controlled use and regulations for fly ash. Therefore, EPA should strictly regulate disposal of coal combustion waste under Subtitle C, and EPA should not exempt the use of bottom ash in concrete and similar products as a beneficial reuse because this reuse results in an inferior, and potentially dangerous, final product.

Jerry Liner
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