FINAL TECHNICAL REPORT
September 1, 1996, through August 31, 1997

Project Title: **AGGREGATE PRODUCTION FROM WET LIMESTONE FGD SLUDGE**

ICCI Project Number: 96-1/3.2A-1
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ABSTRACT

The objective of this project is to evaluate the feasibility of producing synthetic aggregates from wet limestone FGD sludge for use as construction materials. A bench-scale study was conducted to produce synthetic aggregates from the City Water, Light & Power (CWL&P) Dallman Station sulfate FGD sludge (gypsum) and from the Public Service of Indiana (PSI) Gibson Station sulfite sludge, and to evaluate their properties. Both materials are listed in the ICCI Illinois Basin Coal combustion Residues Sample Program.

Synthetic aggregates that meet all ASTM C-33 coarse concrete aggregate specifications for LA abrasion index, soundness index, grain size, and clay lumps, material finer than 25 μm, and coal and lignite content were prepared from the CWL&P Dallman Station gypsum, fly ash, and hydrated lime. The fly ash/gypsum weight ratios in the mixes ranged from 1.47 to 0.82. Lightweight aggregates that meet the ASTM C-331 coarse aggregate specifications for unit weight, clay lumps, grain size, and staining were produced both from the PSI Gibson sulfite sludge and from CWL&P gypsum, fly ash, and hydrated lime. A low density fly ash was blended in the mix to reduce the aggregate unit weight. Strong aggregates that meet all AASHTO M-283 specifications as Class A coarse aggregate were produced from the PSI Gibson sulfite sludge, fly ash, hydrated lime, and an additional component.

A preliminary economic evaluation was conducted to determine the cost of concrete aggregate production from a conceptual 400 MW power plant equipped with a limestone forced oxidation scrubber. Two cases with fly ash/gypsum weight ratios of 1.47 and 0.82 were used. The selection of the mix formation was based on the bench-scale pelletization test results using CWL&P Dallman Station gypsum. The levelized revenue requirement (100% to 25% equity and 15% to 30% ROI) ranged between \$14 and \$15 per ton of aggregate. The combination of aggregate sales price and avoided disposal costs can, in some cases, meet the revenue requirements. The process is not energy or capital cost intensive.

The technical achievements and the favorable economic evaluation indicate that a demonstration test, in which aggregates are produced and tested in actual construction uses, is warranted.

Pages 4, 5, 7, 8, 12, 13, and 14 contain proprietary information.

EXECUTIVE SUMMARY

Activities from September 1, 1996, to August 31, 1997, included bench-scale pelletization of wet limestone FGD sludges from inhibited oxidation and forced oxidation systems. Samples were collected from power plants that were burning Illinois coals. The sludges from both the inhibited and forced oxidations systems were characterized, and pelletized at a variety of conditions and mix formulations. The aggregates produced were tested for their use as highway construction aggregates, concrete aggregates, or lightweight aggregates. The testing was performed in accordance with American Society of Testing and Materials (ASTM) and American Association of State Highway Transportation Officials (AASHTO) standards. A preliminary economic evaluation was conducted to determine the cost of aggregate production from a conceptual commercial-scale facility. The evaluation was based on bench-scale tests that produced aggregates meeting the ASTM specifications as concrete aggregates.

Thirty-two bench-scale pelletization tests were completed. Thirteen pelletization tests were conducted with FGD gypsum and fly ash from the CWL&P Dallman Station, which is equipped with a limestone forced oxidation scrubber. Nineteen tests were conducted with FGD sulfite sludge and fly ash from the PSI Gibson Station, which is equipped with a limestone inhibited oxidation scrubber. About 200 lb of aggregates were produced in each pelletization test. The effects of the mix composition (fly ash/FGD sludge ratio, and water and additive lime dosage) on the properties of the synthetic aggregate were evaluated. Aggregate properties examined include crush strength, LA abrasion index, soundness index, unit weight, grain size and others, as required for specific uses.

Aggregates meeting ASTM C-33 specifications as coarse concrete aggregates were produced from the CWL&P Dallman Station gypsum (similar to CRSP Sample Designation No. 4PPIS), fly ash, and hydrated lime. The properties of the synthetic aggregates produced are compared to the ASTM concrete aggregate specifications below.

Test Number ICCI-	SU-13	SU-14	ASTM C-33 Specs for Concrete Aggregate
LA Abrasion Index, wt %	45	47	50 (max)
Soundness Index,,wt %	3.1	1.3	12 (max)
Grain Size	coarse	coarse	coarse
Clay Lump, wt %	0.85	0.79	2 to 10 (max)
Material Finer than 75 µm, %	0	0	1.0 (max)
Coal and Lignite, %	0	0	0.5 to 1.5
Crush Strength, lb	76	62	—
Unit Weight, lb/ft^3	75	75	—

The fly ash/gypsum weight ratios in the mix ranged from 1.47 in Test 13 to 0.82 in Test 14. The gypsum had a solids content of 82% and a moisture content of 18%. The aggregates produced from Tests 13 and 14 meet all ASTM specifications for LA abrasion index, soundness index, grain size, clay lumps, material finer than 75 µm, and coal and lignite content for use as concrete aggregate.

Aggregates meeting the ASTM C-331 specifications as lightweight aggregates were produced both from the PSI Gibson sulfite sludge (similar to CRSP Sample Designation No. 2PPS), fly ash and lime, and from CWL&P gypsum, fly ash, and hydrated lime. The aggregate properties are compared to the ASTM lightweight aggregate specifications below. Test Nos. 28 and 29 were conducted with PSI Gibson Station sulfite sludge. Test No. 30 was conducted with CWL&P Dallman Station FGD gypsum. The fly ashes used in the mixes were blended with a low-density fly ash to reduce the aggregate unit weight. The FGD sulfite sludge and gypsum had solids contents of 58% and 82%, respectively.

Test Number ICCI-	SU-28	SU-29	SU-30	ASTM C-331 Specs for Lightweight Aggregate
Source of Sludge	Gibson	Gibson	Dallman	
Unit Weight, lb/ft^3				
as-is	63	65	62	---
dry	52	55	49	55 (max)
Clay Lumps	1	1	1.5	2 (max)
Grain Size	coarse	coarse	coarse	coarse
Staining	none	none	none	none
Crush Strength	71	72	154	---

Aggregates produced from Test Nos. 28, 29 and 30 meet the ASTM specifications for unit weight, clay lumps, grain size and staining for use as lightweight aggregate. Some ASTM C331 specification properties were not evaluated.

Strong aggregates meeting all AASHTO M-283 specifications as Class A road aggregate were produced from PSI Gibson FGD sulfite sludge, fly ash, hydrated lime and an additional component. The properties of aggregates produced with and without the additional component are compared with AASHTO Class A aggregate specifications below.

Test Number ICCI-	SU-8 (Without the Additional Component)	SU-12 (Without the Additional Component)	SU-23 (With the Additional Componentve)	AASHTO M-283 Specs for Class A Aggregate
LA abrasion index, wt %	36	30	26	40 (max)
Soundness index, wt %	84	87	10	12 (max)
Grain Size	coarse	coarse	coarse	coarse
Unit weight, lb/ft^3	75	73	78	70 (min)
Crush Strength, lb	95	148	338	---

Crush strength increased and LA abrasion and soundness indices decreased with the additional component. Without the additional component, the aggregates produced did not meet the soundness index specification for use as AASHTO Class A aggregate in highway construction.

A preliminary economic evaluation was conducted to estimate the total levelized aggregate production costs as a function of return on investment (ROI) and debt/equity ratio. The evaluation was based on a conceptual 400 MW power plant equipped with a limestone forced oxidation scrubber and burning 1 MM ton of 3% sulfur coal per year. Two cases with fly ash/gypsum weight ratio of 1.47 and 0.82 were used. The selection of the mix formulation was based on the bench-scale tests using CWL&P Dallman Station gypsum for concrete aggregate production (Cases 1 and 2 from Test Nos. ICCI-SU-13 and -14, respectively). The following table summarizes the total levelized aggregate revenue requirement at different levels of equity (100%, 50%, and 25%) and ROI (15%, 20%, and 30%).

% Equity	% ROI	Case 1, $/ton aggregate	Case 2, $/ton aggregate
100	15	14.89	14.42
50	20	14.88	14.21
25	30	15.06	14.40

As indicated, there is little difference in the aggregate revenue requirement as ROI and percent equity change. The relatively low capital cost does not contribute significantly to the total levelized production cost. The effects of higher ROI and lower equity are offsetting. Other assumptions used in the analysis include a twenty-year project life, a one-year construction period, 3% inflation, seven-year depreciation schedules on capital equipment, 8% cost of debt and ten-year loan term. If the avoided disposal cost ($10 to $20/ton for a new landfill) is included, production of synthetic aggregate from FGD sludge is economically feasible.