Utilization of Lightweight Materials Made from Coal Gasification Slags

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Prepared by:

Praxis Engineers Inc.
852 North Hillview Drive
Milpitas, California 95035
Tel. No: (408) 945-4282
Fax No: (408) 263-2821

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1.0 PROJECT OBJECTIVES, SCOPE AND DESCRIPTION OF TASKS

1.1 Introduction

The integrated-gasification combined-cycle (IGCC) process is an emerging technology that utilizes coal for power generation and production of chemical feedstocks. However, the process generates large amounts of solid waste, consisting of vitrified ash (slag) and some unconverted carbon. In previous projects, Praxis investigated the utilization of "as-generated" slags for a wide variety of applications in road construction, cement and concrete production, agricultural applications, and as a landfill material. From these studies, we found that it would be extremely difficult for "as-generated" slag to find large-scale acceptance in the marketplace even at no cost because the materials it could replace were abundantly available at very low cost. It was further determined that the unconverted carbon, or char, in the slag is detrimental to its utilization as sand or fine aggregate. It became apparent that a more promising approach would be to develop a variety of value-added products from slag that meet specific industry requirements. This approach was made feasible by the discovery that slag undergoes expansion and forms a lightweight material when subjected to controlled heating in a kiln at temperatures between 1400 and 1700°F. These results confirmed the potential for using expanded slag as a substitute for conventional lightweight aggregates (LWA). The technology to produce lightweight and ultra-lightweight aggregates (ULWA) from slag was subsequently developed by Praxis with funding from the Electric Power Research Institute (EPRI), Illinois Clean Coal Institute (ICCI), and internal resources.

The major objectives of the subject project are to demonstrate the technical and economic viability of commercial production of LWA and ULWA from slag and to test the suitability of these aggregates for various applications. The project goals are to be accomplished in two phases: Phase I, comprising the production of LWA and ULWA from slag at the large pilot scale, and Phase II, which involves commercial evaluation of these aggregates in a number of applications.

Primary funding for the project is provided by DOE's Federal Energy Technology Center (FETC) at Morgantown, with significant cost sharing by Electric Power Research Institute (EPRI) and Illinois Clean Coal Institute (ICCI).

1.2 Scope of Work

The Phase I scope consisted of collecting a 20-ton sample of slag (primary slag), processing it for char removal, and pyroprocessing it to produce expanded slag aggregates of various size gradations and unit weights, ranging from 12 to 50 lb/ft³. In Phase II, the expanded slag aggregates are being tested for their suitability in manufacturing precast concrete products (e.g., masonry blocks and roof tiles) and insulating concrete, first at the laboratory scale and subsequently in commercial manufacturing plants. These products will be evaluated using ASTM and industry test methods. Technical data generated during production and testing of the products will be used to assess the overall technical viability of expanded slag production. Relevant cost data for physical and pyroprocessing of slag to produce expanded slag aggregates will be gathered for comparison with (i) the management and disposal costs for slag or similar wastes and (ii) production costs for conventional materials which the slag aggregates would replace. In addition, a market assessment will be made to evaluate the economic viability of these utilization technologies.

1.3 Phase I Task Description

A summary of the tasks performed in Phase I is given below:

- Task 1.1 Laboratory and Economic Analysis Plan Development:** Development of a detailed work plan for Phase I and an outline of the Phase II work.
- Task 1.2 Production of Lightweight Aggregates from Slag:** This task covered selection and procurement of project slag samples, slag preparation including screening and char removal, and slag expansion in a direct-fired kiln and fluid bed expander. The char recovered from the slag preparation operation was evaluated for use as a kiln fuel and gasifier feed. Environmental data for slag-based lightweight aggregate (SLA) production was collected.
- Task 1.3 Data Analysis of Slag Preparation and Expansion:** Analysis and interpretation of project data, including development of material and energy balances for slag processing and product evaluation.
- Task 1.4 Economic Analysis of Expanded Slag Production:** Economic analysis of the utilization of expanded slag was conducted by determining production costs for slag-based LWAs and ULWAs. Expanded slag production costs were compared with the market value of similar products both with and without taking into account the avoided costs of disposal and with the costs of management of slag as a solid waste.
- Task 1.5 Topical and Other Reports:** Preparation topical, financial status, and technical progress reports in accordance with the Statement of Work.

1.4 Phase II Task Description

A summary of the tasks to be performed in Phase II is given below.

- Task 2.1 Test Plan for Applications of Expanded Slags (Field Studies):** This task involves the development of selection criteria and a field test plan for applications of expanded slag. This plan will serve as a guide in the selection and implementation of field demonstrations for the most promising expanded slag utilization applications. Field applications will be selected on the basis of laboratory results, the marketability of the products, and the suitability of the project slags for producing them. The following applications are under consideration for testing:
- Lightweight concrete blocks made from 50 lb/ft³ SLA
 - Lightweight roof tiles made from 40 lb/ft³ SLA
 - Loose fill insulation made from 16 lb/ft³ SLA
 - Lightweight insulating concrete made from 16 lb/ft³ SLA
- Task 2.2 Field Studies to Test Expanded Slag Utilization:** Under this task, field testing of the applications identified in Phase II, Task 2.1, will begin with test work to optimize the concrete mixes made from expanded slag.

Task 2.3 Data Analysis of Commercial Utilization of Expanded Slags: The objective of this task is to assimilate the data and test results collected during Phase II, Task 2.2, convert these findings to common engineering terms, and correlate these results with comparable information for conventional lightweight aggregates as reported in the literature. The data analysis will provide specific answers to the following issues:

- Performance of expanded slag vs. that of conventional materials
- Technical viability of lightweight and ultra-lightweight slags as aggregates.

Task 2.4 Economic Analysis of Expanded Slag Utilization: The objective of this task is to expand upon the preliminary economic assessment of expanded slag utilization conducted during Phase I. The economics will be studied based on the production costs for SLA in comparison with current market prices for conventional materials. During the Phase I preliminary evaluation, two production scenarios emerged:

- Production of SLA at the gasifier location (on-site production)
- Production of SLA at a lightweight aggregate facility (off-site production).

The impact of the avoided costs of slag disposal on the economics of SLA production will also be evaluated. Slag utilization data and product samples will be made available to commercial lightweight aggregate users for validation of estimated market prices. The impact of SLA market prices on the economics of SLA production will also be studied.

Task 2.5 Final Report: The data generated and collected during the project will be compiled in a final report to be submitted at the end of the project that will be a comprehensive description of the results achieved, consistent with the Reporting Requirements. Data from topical and field reports will be summarized. The report will include the original hypothesis of the project and present the investigative approaches used, complete with problems encountered or departures from the planned methodology, and an assessment of their impact on the project results.

1.5 Scope of This Document

This is the seventeenth quarterly report and summarizes the work undertaken during the performance period between 1 September 1998 and 30 November 1998. It is the tenth quarterly report for Phase II. This document summarizes the Phase II accomplishments to date along with the major accomplishments from Phase I.

2.0 SUMMARY OF WORK DONE DURING THIS REPORTING PERIOD

2.1 Summary of Major Accomplishments

In the current reporting period, work focused on presenting the slag/char separation process to two DOE-funded IGCC facilities who do not currently sell their slag due to its high char (carbon) content. The following was accomplished during this reporting period:

1. Conceptual design for a commercial-scale slag/char separation facility was developed for presentation to two IGCC facilities (Wabash River and Polk power plants).
2. Commercial production and economic evaluation of expanded slag in the panel application was initiated per user request.
3. Mutual non-disclosure agreements were signed with the two IGCC sites in order to share slag/char separation process information and visit their respective plant sites.
4. Testing of SLA for nursery applications continues.
5. Applications-oriented testing of Slag IV was completed.

2.2 Chronological Listing of Significant Events in This Quarter

The following significant events occurred during the current reporting period:

Date	Description
9/30/98	Slag-char separation vendor testing and data analysis for Slag IV completed
10/15/98	Testing of Slag IV for lightweight aggregate production completed
10/24/98	Presentations on the slag/char separation process made to two DOE-funded IGCC facilities
11/20/98	Applications-oriented testing of Slag IV completed

3.0 TO DATE ACCOMPLISHMENTS

A summary of the work completed in Phase I is given below.

Date	Phase I Accomplishments Description
10/24/94	Draft Laboratory and Economic Analysis Plan (project work plan) submitted
11/18/94	Slag char removal completed on the advance sample and prepared slag laboratory expansion testing initiated
12/02/94	Final "Laboratory and Economic Analysis Plan" prepared and submitted
05/21/95	Primary slag sample (20 ton) received at Penn State for preparation
06/01/95	Pilot unit for char removal set up and processing work started
08/20/95	Primary slag sample processing for char removal completed
9/10/95	Laboratory expansion studies of slag and slag/clay blends started
10/15/95	1-ft and 3-ft diameter kilns commissioned for pilot testing
11/15/95	Pilot testing of Slag I and Slag II and pellets in 3-ft dia. direct-fired kiln completed
11/17/95	Pilot testing using fluidized bed expander completed
12/12/95	SLA product characterization initiated
1/20/96	Laboratories for testing of SLA products identified
2/16/96	Test plan for second batch of fluid bed expander testing at Fuller completed

A summary of the work completed in Phase II to date is given below.

Date	Phase II Accomplishments Description
4/30/96	Application for continuation of the project to Phase II submitted
5/31/96	Phase I Final Report (draft) submitted to METC
7/1/96	Phase I Topical Report (final version) submitted
7/14/96	Approval for continuation of the project to Phase II was received from METC
7/14/96	Structural concrete laboratory tests started
7/15/96	Lab testing of SLA for roof tile and insulating concrete applications completed
7/15/96	Evaluation of SLA for completed
7/30/96	Evaluation of SLA for loose fill insulation completed
10/10/96	Mix designs for block production selected
11/10/96	Laboratory evaluation of the Slag II completed
10/30/96	Structural concrete laboratory tests completed
11/10/96	Laboratory evaluation of Slag III for LWA production completed
1/10/97	Laboratory testing of SLA for structural concrete application completed
2/19/97	First batch of laboratory tests of selected block mixes completed
4/30/97	Processing of Slag III for char removal completed
5/20/97	Preparatory work for Slag III pyroprocessing completed
7/30/97	Preparation of Slag III for SLA production completed
8/20/97	Utilization of SLA as growing medium for potted plants completed successfully
10/2/97	Exploratory testing of expanded slag for nursery applications completed
10/2/97	Laboratory testing of expanded Slag I for block application completed
11/1/97	Testing of expanded slag in panel application completed
12/2/97	Second phase of testing of expanded slag for nursery applications started
1/20/98	Evaluation of expanded Slag III for block and roof tile applications initiated
2/15/98	Second round evaluation of expanded Slag III in panel application completed by end user
3/12/98	Testing of Slag IV included in the current project
3/23/98	Roof tile evaluation of expanded slag/clay 50/50 blends was reconfirmed
4/25/98	Commercial production and economic evaluation of expanded slag in panel application was initiated per user request
6/12/98	Production of a large batch of blocks using expanded slag successfully completed
7/12/98	Testing of Slag IV for char removal completed in the current period
7/20/98	Testing for optimization of the strength for roof tile application conducted
8/15/98	Laboratory testing initiated for concrete panels flexural strength development

Date	Phase II Accomplishments Description
9/30/98	Slag-char separation vendor testing and data analysis for Slag IV completed
10/15/98	Testing of Slag IV for lightweight aggregate production completed
10/24/98	Presentations on slag/char separation process to two DOE-funded IGCC facilities completed
11/20/98	Applications-oriented testing of Slag IV completed

4.0 TECHNICAL PROGRESS REPORT

4.1 Slag/Char Separation and Application Development Test Results for Slag IV

A sample of Slag IV was obtained and tested primarily for slag/char separation processing. In addition, exploratory work was performed to confirm the basic utilization potential of this slag, including production of lightweight aggregate. Initial slag/char separation testing was performed at Praxis' pilot facility at a university laboratory, followed by additional testing at a vendor's facilities using commercially available equipment.

Slag/Char Separation: The Slag IV test results confirmed data obtained from other slags that indicate that char-free slag can be generated at the commercial scale. In the case of Slag IV, a char fraction with 67% carbon (33% ash) can be generated for recycle or use in a boiler. This could be further upgraded to nearly 80% carbon by means of an additional processing step. The slag/char processing steps are described in Section 4.2.

Applications-Oriented Testing of Slag IV

Tests were conducted to identify and confirm the potential for utilizing Slag IV in a number of applications. The results are summarized below.

1. **Cement concrete aggregate:** Tests were conducted to evaluate whether concrete with a compressive strength of 2,000 psi can be made from char-free Slag IV using a mix containing 5-6 sacks/cu yard, as typically used for making masonry products (blocks, bricks, stepping stones, etc.), concrete grout, mortar mix, ready mix etc. This work was done at the laboratory scale using 2" cubes to obtain 7 and 28-day strengths using an earlier mix design. The test results are given in the following table.

Weight % Aggregates		Cement	Compressive Strength, psi	
Coarse Aggregate	Slag		7-Day	28-Day
50	50	6 sacks/cu yd	3975	
25	75	6 sacks/cu yd		
0	100	6 sacks/cu yd		

The results indicate that Slag IV can be used as an aggregate to produce precast products and for concrete mixes requiring strengths of 2000-4000 psi.

2. **Road construction and maintenance:** The particle size and other general properties of Slag IV indicate that it is similar to most other slags. This slag is also considered suitable for sub-base and base material and seal coat aggregate.

3. **Industrial material (roofing granules, industrial fillers, abrasive grit):** Sieve analysis comparison of the char-free slag indicates that it can be used as industrial material for a variety of applications.
4. **Lightweight aggregate production:** Slag IV was subjected to tests in a muffle furnace based on the procedure used on a number of other slags. The results indicate that Slag IV is a suitable feed material for the production of lightweight aggregates. However, additional work is needed for the production of ultra-lightweight aggregates which are below 12 lb/ft³ unit weight.

Test No.	Feed	1	2	3	4	5
Temp., °F	Ambient	1450	1500	1600	1700	1800
Unit wt., lb/ft ³	109	94.2	88.9	80	64	55

The following conclusions were drawn from testing and evaluation of Slag IV:

- Excellent slag/char separation was achieved producing a salable slag and recyclable char. Commercial-scale separation of the char from the slag can be carried out by retrofitting the slag/char separation process modules as needed at any IGCC plant.
- The slag/char separation process is water-based and uses proven commercially manufactured equipment so capital and operating costs are low.
- Char-free Slag IV can be used for many medium and high-value applications.
- There is a considerable market for Slag IV in high-value applications in the vicinity of the plant where it is generated.

4.2 Utilization of Slag/Char Separation Process at DOE-Funded IGCC Plants

In a previous reporting period, Praxis tested a slag sample obtained from the Wabash River Repowering Project IGCC plant to study its expansion characteristics. This slag was added to the test program with the objectives of extending the project findings to another slag and exploring the potential for producing an expanded product with a unit weight ranging between 50 and 55 lb/ft³ and high compressive strength as required for structural concrete applications. These project goals were met and the lightweight aggregate made from this slag was demonstrated to be suitable for many construction applications. In addition, a sample of slag was obtained from Tampa Electric's IGCC facility in Tampa, Florida, to test its amenability for the slag/char separation process and to determine its expansion characteristics. Both of these capabilities were demonstrated successfully.

Prior to processing each slag for LWA production, it was processed for char separation using the process developed by Praxis during this project. Both IGCC facility operator/owners (Dynergy and Tampa Electric Co.) expressed interest in using this slag/char separation process at their plants. In this reporting period, a conceptual design for a slag/char separation facility and preliminary costs were developed and presented to these organizations. The slag/char separation process, performance, and typical costs that were presented to these organizations are summarized here without specific reference to the slag from either plant.

Justification for Slag/Char Separation at IGCC Plants

Coal gasification slag consists of vitrified mineral matter that originates from the coal along with unburned or unconverted carbon (char). As-generated or raw gasification slag contains 15-30% char

which is a hindrance to its utilization. When char-bearing slag is disposed of as solid waste, the energy content in char is wasted. Praxis Engineers, Inc. has developed, tested, and demonstrated at the pilot scale a process for separating the char from slag with the objective of making two byproducts, namely, clean or essentially char-free slag and char. A 400-lb/hr capacity pilot plant for slag/char separation was set up to process over 20 tons of slag feed using a number of slags generated from different gasification processes and coal feedstocks. The recovered char fraction contained approximately 35-40% ash (or 65-60% carbon). The char-free slag was utilized as a marketable by-product for a number of applications including aggregate in cement concrete and raw material for the production of lightweight aggregates. An evaluation of the recovered char indicated that it may be recycled to the gasification process or used as a boiler fuel when mixed with coal.

Process System Description

The Praxis slag/char separation process presented to the gasifier operators consists of the following steps:

1. **Screening and Recovery of Char-Free Slag.** This step is aimed at recovering the char-free slag fraction to minimize processing costs.
2. **Gravity Separation of Slag and Char.** We established that slag has a higher density than char and can be separated using methods which take advantage of the density difference between the two materials. These include hydrocyclones, jigs, water-only cyclones, mineral spirals, tables, elutriation devices, and similar equipment.

Laboratory- and pilot-scale tests performed by Praxis were confirmed by vendor testing using commercially available equipment. We have consistently produced a high-ash (~100%) slag and a 35-40% ash (or 65-60% carbon) char from laboratory and commercial equipment units. Commercial separation is considered to be a relatively simple operation which is cost effective due to its high capacity. The results of the size and gravity separation steps (Steps 1 and 2) are listed Table 1 which contains test results for the various slags tested to date including those from the above two plants.

Table 1. Slag/Char Separation Results from Process Steps 1 and 2

Slag	Feed		Clean Slag		Char	
	Wt%	Ash %	Wt%	Ash %	Wt%	Ash %
Slag 1	100	91.2	85.7	100	14.3	38.3
Slag 2	100	84.9	70.0	99.4	30.0	51.1
Slag 3	100	85.8	74.3	100	25.7	45.1
Slag 4	100	83.7	73.1	99.3	26.9	41.0
Slag 5	100	75.1	62.7	100	37.3	32.9
Slag 6	100	68.7	46.3	100	53.7	41.2

3. **Reprocessing of Char to Upgrade its Carbon Content.** This step can be used to further upgrade the char to contain 70-80% carbon (or 20-30% ash). The process parameters for this step are highly slag dependent and need to be established for each slag by laboratory testing. The slag recovered from this step will be blended with the main slag stream recovered from Step 2 in some cases and dewatered in Step 4. The results for this step are given in Table 2.

Table 2: Results of Process Step 3 to Upgrade Char Carbon Content

Slag	Feed		Clean Slag		Char	
	Wt%	Ash %	Wt%	Ash %	Wt%	Ash %
Slag 1	100	91.2	85.7	100	14.3	38.3
Slag 2	100	84.9	70.0	99.4	30.0	51.1
Slag 6	100	85.8	74.3	100	25.7	45.1

In the event that the slag fraction rejected from Step 3 contains an unacceptably high carbon content, it can either be discarded or further processed. Since this stream is a small portion of the total slag generated at the plant, the disposal problem is reduced greatly. However, this fraction can also be upgraded using packed column flotation. The use of flotation can achieve a nearly zero solid waste disposal at the gasifier plant. However, flotation is expensive and the decision to use it can only be made after a complete analysis of all economic factors.

4. **Dewatering of Slag Product.** The recovered slag product can be dewatered using mechanical dewatering equipment to achieve the product moisture desired by the client.
5. **Handling of Recovered Char Product.** The recovered char product will be thickened and returned to the coal grinding system in slurry form for recycle to the gasifier.

Application of Slag/Char Separation Process at Wabash Plant: In the presentation made to Dynergy Corp. on 24 October 1998 at Wabash plant, Praxis showed test results and discussed the merits of the process and its direct applicability to the Wabash slag. However, the requirements for integration of the slag/char separation process with their overall process were not specified to Praxis prior to the meeting. Therefore, such information is needed from Dynergy to meet customization requirements and make the Praxis slag/char separation process suitable for use at the Wabash plant.

Application of Slag/Char Separation Process at TECO Plant: In the presentation made to Tampa Electric at the Polk plant on 20 October 1998, Praxis discussed the results and merits of the process and its direct applicability to the Tampa slag. At this site, the Praxis process is directly applicable, whether using selected process steps or as a total package. However, further progress on this issue is at a standstill pending ongoing modifications to the plant's slag handling facility. TECO will revisit the issue upon completion of the modifications scheduled for the year end.

4.2 Evaluation of SLA in Production of Cement Panels (Waterproof Boards)

Following the completion of testing and evaluation of slag lightweight aggregate for the panel application, the cement panel manufacturer has shown interest in buying 40 lb/ft³ expanded slag at the rate of 20,000 tons/year for one of its plants located on the west coast. Their current costs for this type of material are estimated at \$50-55/ton. They are willing to set up a joint venture produce slag-based lightweight aggregate at their plant. However, the following technical and strategic problems pose hurdles to commercial-scale slag utilization:

- IGCC facilities in the United States are not in a position to supply char-free slag at present.
- Since slag is generated in the midwestern and east coast regions, transportation costs to bring it to the west coast make this venture less economically attractive unless slag generators provide incentives to first-time slag users.

- IGCC operators (slag generators) have shown little interest to date in evaluating joint ventures to produce slag lightweight aggregate or commit support to such efforts.
- Regulatory incentives to diminishing slag disposal as solid waste are not yet in place.

5.0 PLAN FOR THE NEXT QUARTER

The following activities are planned for the next quarter:

- Continue work on manufacturer evaluation of slag lightweight aggregates for roof tile, panel, and other applications
- Complete commercial evaluation of SLA for concrete panel applications at the commercial manufacturing plant
- Continue laboratory evaluation of SLA I for horticultural applications
- Provide technical information to DOE supported projects on using the slag/char separation process.