with a 4.6-mm (0.18-inch) nozzle gap, increasing the sludge mass 20% above that of Test 33 but at a 25% lower dispersion gas rate, produced comparable particle sizes with an equivalent dispersion gas pressure.

The improvement in performance with the EERC-2 nozzle compared to the EERC-1 nozzle may be partially explained by differences in construction. In the former nozzle, the sludge pipe containing the dispersion cone had a very slight bevel at its tip, forming essentially a sharp orifice with the cone. In the latter nozzle, the nozzle body tip had a bevel of approximately 9.53 mm (0.375 inch), perhaps providing additional length over which the sludge and dispersion gas could become intimately mixed. Further, the design of the second nozzle may have allowed the dispersion cone to be centered better within the nozzle body. An uneven annulus would have the effect of providing a larger flow gap around part of the nozzle, producing poorer sludge dispersion.

Photos of sludge dispersion spray from the shotcrete nozzle and EERC-1 and EERC-2 nozzles are presented in Appendix B. The photos were extracted form video recordings of the dispersion tests. A movie clip of the EERC-2 nozzle can be found at the following link: http://www.undeerc.org/clips/eerc2.wmv.

Dispersion Tests in Pressurized Vessel

A number of unsuccessful attempts were made at dispersing the sludge into a pressurized vessel. The purpose for trying these tests was to observe if injecting the sludge into a denser atmosphere, owing to the higher pressure of the gas in the pressure vessel, would cause additional shearing and degradation of the sludge particles. For this series of tests, the 254-mm (10-inch) pressure vessel was modified to allow insertion of the EERC-2 nozzle and to allow videotaping of the sludge spray pattern. Photos of the modified vessel are shown in Figures 29–31.

EERC MM21037.PCX

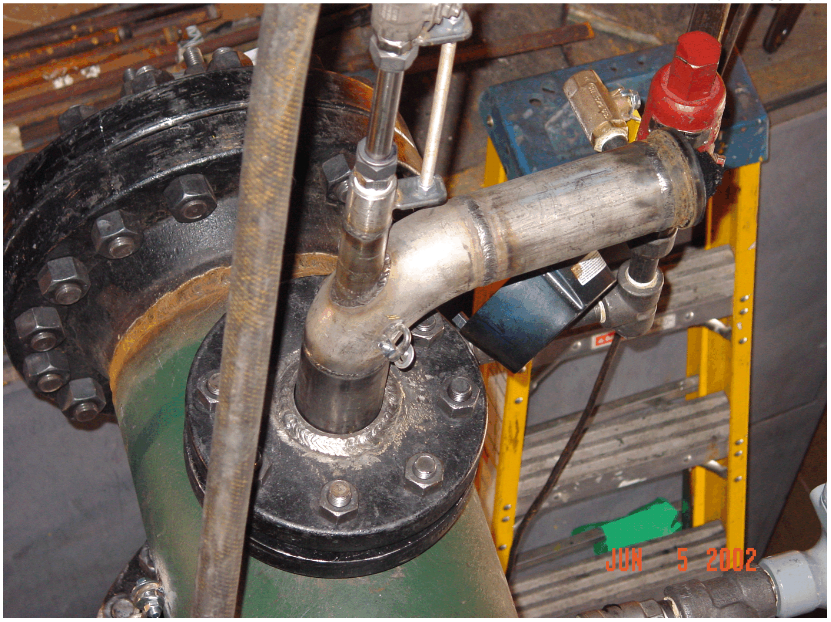


Figure 29. Pressurized sludge dispersion system – nozzle view.

EERC MM21038.PCX

Figure 30. Pressurized sludge dispersion system – tee assembly view.

EERC MM210039.PCX

Figure 31. Pressurized sludge dispersion system – sight port view.

To allow viewing and videotaping, the blind flanges on the tee were bored out and then outfitted with76.2-mm (3-inch) flanged pipe nozzles mated with a high-pressure glass site port. The ported flanges were arranged opposite each other on the tee to allow direct line-of-site viewing. One of the site port nozzles was equipped with a bracket to support the videocamera. A light source was hung at the other site port. An adjustable seal system, using square Teflon rope packing, was designed to allow vertical insertion of the dispersion nozzle to a select position between the site ports. The system was equipped with safety chains to prevent unwanted ejection of the sludge nozzle while at pressure. The bottom of the pressure vessel was equipped with a 63.5-mm (2.5-inch) full-ported ball valve to allow withdrawal of the sludge under pressure. The 254-mm (10-inch) tee was also ported to allow attachment of a safety relief valve and back-pressure control valve.

Based on the maximum available compressed air, it was determined that dispersion tests could be performed at vessel pressures up to 0.76 MPa (110 psig). To perform a test, the dispersion gas flow was started to bring the vessel up to pressure, with the back-pressure control continually relieving to maintain the desired pressure. The sludge flow was then started to begin the dispersion test. The sludge, however, demonstrated its tenacity toward stickiness and unflowability by impacting on the vessel wall near the nozzle tip and almost immediately bridging to obstruct the line of site between site ports. Further, the spray pattern blocked a significant portion of the light, not allowing good enough visibility to determine the impact of pressurized dispersion on sludge particle size. The nozzle was repositioned several times in an attempt to provide an impingement point where the sludge would fall, under its own weight, to the bottom of the pressure vessel. This was unsuccessful.

Alternative Nozzle Design

During the course of testing with the EERC-1 and EERC-2 nozzles, it was observed that the hair within the sludge could collect at the alignment fins and cause poor dispersion within the vicinity. A possible alternative design would be to have a flat, rectangular opening to the nozzle. This design would eliminate the cone insert (with alignment fins and hung-up hair) and the design issues for maintaining a uniform annular gap in the much more severe environment of a gasifier. In the instance of achieving a nozzle gap of 4.6 mm (0.18 inches), the nozzle width would be approximately 183 mm (7.2 inches). If this pipe width is too large to insert through existing gasifier ports, two 92-mm (3.6-inch) superposed nozzles could be used; however, even flow distribution may become an issue.

Estimation of Dispersion Gas Pressure Requirements

Results of the dispersion testing, specifically with EERC-2 nozzle, indicated that reasonable sludge dispersion results were obtained at 314 kg/min (690 lb/min): half that required for a 909 metric tons/day (1000 short tons/day) feed rate at Wabash River and half the maximum desired dispersion gas as estimated by Global Energy in its modeling efforts. Consequently, two dispersion nozzles would be used. Based on a sludge nozzle dispersion gas pressure of 0.31 MPa (45 psig), the actual recycle syngas pressure required for utilization at a gasifier pressure of 2.83 MPa (410 psig) was estimated. For this estimation, it was assumed that the annular nozzle gap would be the same when used at pressure as previously demonstrated in the sludge dispersion tests. Further, it was assumed that the annular gap area would have a C_v, much as a trim-seat combination for a control valve has a C_v for a specified set of flow conditions (i.e., temperature, pressure, pressure drop, and specific gravity). Consequently, the standard formula for flow coefficient calculation, shown in Equation 4 (57) was first utilized to calculate a C_v for the EERC-2 nozzle at atmospheric conditions and, with the same C_v, was then used to calculate P_1 (dispersion gas pressure upstream of the nozzle) as required at gasifier pressure:

$$Cv = \left[\frac{Q\sqrt{T} \cdot SG}{1360\sqrt{P_1 \cdot dP}} \right]$$

where P_1 = absolute upstream pressure, psia

P_2 = absolute downstream pressure, psia
Q = gas flow rate at standard pressure and temperature, scfh
T = absolute gas temperature, R
SG = gas specific gravity, relative to air
dP = ½ P_1, for critical flow where $P_1 - P_2 > ½P_1$

The conditions utilized in the calculations and resulting values are shown in Table 18.

Table 18. Conditions for Estimation of Dispersion Gas Pressure

Parameter	Atmospheric Conditions	Gasifier Conditions
P_1	60	1350[a]
Q	4400	135500
T	520	520
SG	1	0.729[b]
dP	30	675[a]
C_v	1.74[a]	1.74

[a] Calculated value.
[b] Calculated based on dry recycle syngas composition.

The results indicated that the recycle syngas pressure required for dispersion at gasifier conditions would be approximately 9.30 MPa (1350 psia). Because recycle syngas is available at a much lower pressure, 5.51 MPa (800 psig), boosting to dispersion pressure will be required. Consequently, seven gas compressor vendors were contacted to obtain a budgetary cost for a boost compressor. The following Syngas specifications were provided to the vendors:

Mass rate	15,000 lb/hr
Gas composition	
Carbon dioxide	15–16 vol%
Carbon monoxide	45 – 49 vol%
Hydrogen	33 – 34 vol%
Methane	0.5 – 2 vol%
Sulfur gases	<70 ppmv
Nitrogen, argon	Balance
Calculated molecular weight	21.6 lb/lb-mole
Pressure	800 psig

The information requested from compressor vendors included:

- Number of compressors
- Model or frame designation
- Estimated capital cost (not installed)
- Estimated annual maintenance cost
- Power (hp or kW) requirements
- Other utilities (cooling water, etc.)

Estimates were requested for boosting recycle syngas to 1500 and 2500 psig. Table 19 presents the recommended compressor and configuration plus capital cost and installed horsepower data. Only

Table 19. Compressor Systems for Dual-Fluid Sludge Dispersion Nozzle Gas Pressure Boost

Company	Model	Cost for 1500 psig, $1000	Cost for 2500 psig, $1000	Compressor Type	Comment
VR Systems					$1000–$1200 per hp
	Ariel JG/2, 200 hp	200–240		Reciprocating	
	Ariel JGH/2, 350 hp		350–420	Reciprocating	
Knox Western					
	Eagle 3245, 300 hp	171		Reciprocating	
	Eagle 3445, 500 hp		298	Reciprocating	Maximum pressure 2250 psig
PDC Machines, Inc.	13-1500-1500 duplex	240		Diaphragm	2 series machines
	13-1500-1500 duplex		240	Diaphragm	2 series machines
PPI					
	Frame 9X213	700		Diaphragm	7 parallel machines
	Frame 9X175		1400	Diaphragm	14 parallel machines
Gardner Denver					No systems
Elliott (Ebara Group)					Flow rate too low
Atlas Copco					Maximum pressure 1200 psig

four of seven vendors could provide compressor systems for this application. For a 1500-psig boosted recycle syngas pressure, the installed motor power rating ranged from 150 to 225 kW (200 to 300 hp). The approach suggested by PPI was considered unwieldy and overly costly. For the remaining responding vendors, the compressor cost ranged from $171,000 to $240,000. Power and cost each increased by approximately 70% for compressor systems capable of achieving 2500-psig recycle syngas pressure.

With the same compressor producing 1500 psig, it could also be possible to increase the sludge rate 20%, to 1090 metric tons (1200 short tons) per day, and decrease the dispersion gas rate 25%, to 5110 kg/hr (11,250 lb/hr), as indicated in Sludge Dispersion Test 37 previously described.

Sludge-Receiving, Storage, and High-Pressure Pumping Concept

Based on consultations with Global Energy concerning the layout and geology of the Wabash River site and with Schwing America concerning typical sludge industry approaches and equipment limitations, a concept for utilization of municipal sewage sludge at the Wabash River gasifier was developed. For this concept, it was further assumed that sludge would be received by truck. The sludge processing system was divided into three major facility areas:

1. Receiving station (and short-term storage)
2. Live storage
3. High-pressure feeding (with run tank)

A block flow diagram of the process is shown in Figure 32. Specifications were developed for the three major process steps and were presented to Schwing America for cost estimation. The specifications and information requested from Schwing are presented below.

Receiving Station

a. Receiving station should be enclosed
b. Enclosure should be ventilated with odor control and winter-heating capability
c. Facility should have capability to receive two trucks at a time
d. Sludge storage capacity should be 227 metric tons (250 short tons) or 6 hours of sludge feed
e. Transfer pump(s) and ancillary feeders/power packs should be enclosed in receiving station
f. Minimum transfer rate of 1000 tons per day (estimated 170 gpm)
g. Transfer piping should be heat-traced and insulated

Live Storage

a. Live-storage (including sliding frames, extraction screws/conveyors) silos should be enclosed in ventilated, odor-controlled, and winter-heated structure
b. Storage should be 1820 metric tons (2000 short-tons) or two days of sludge feed
c. Minimum transfer rate of 1000 tons per day (estimated 170 gpm)

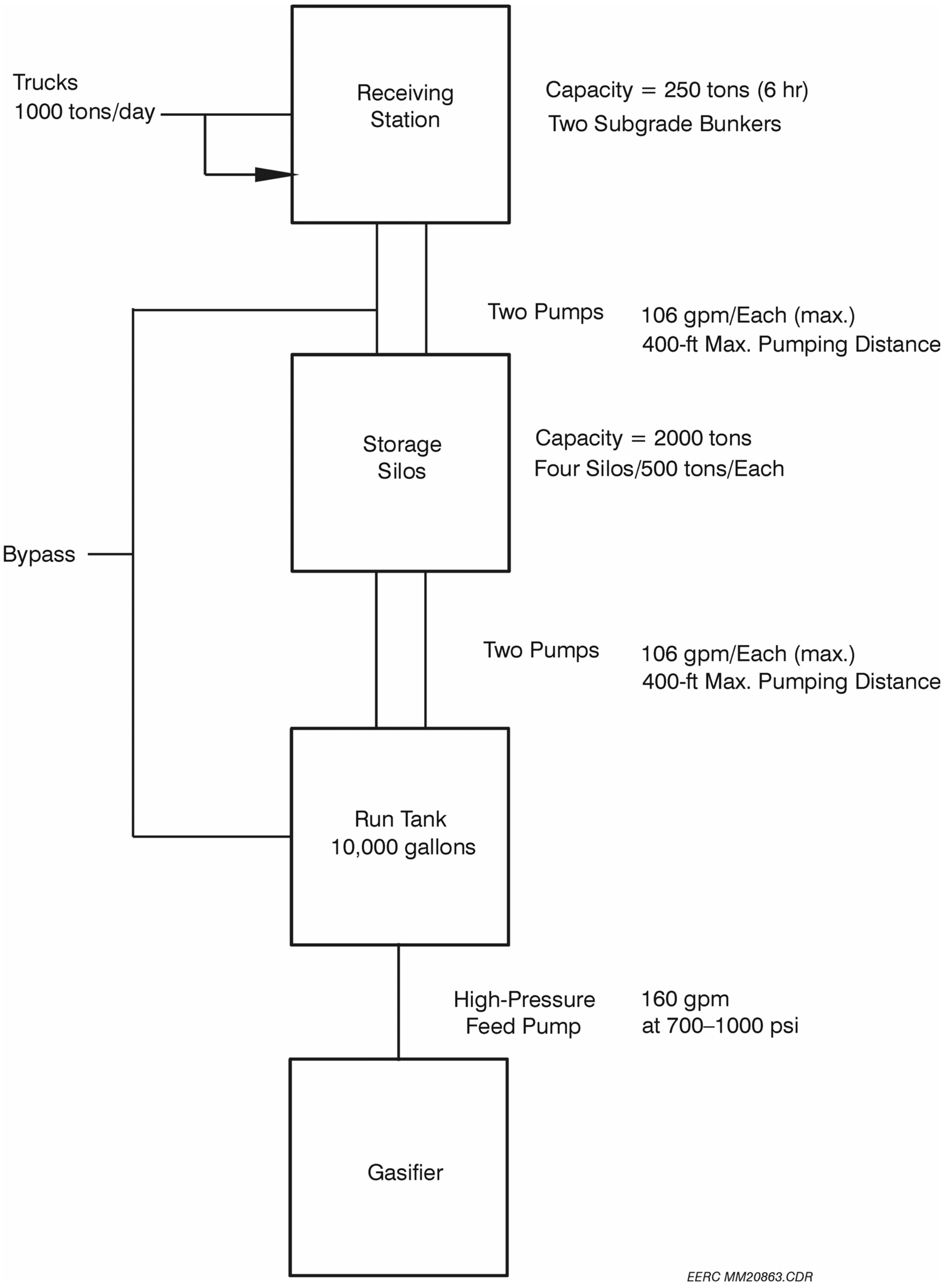


Figure 32. Block flow diagram of proposed sludge-processing system.

High-Pressure Feeding

a. Feed pump and ancillary twin-screw feeder and power pack should be enclosed
b. Minimum pumping rate of 1000 tons per day (estimated 170 gpm)
c. Sludge will be fed from 37,900-liter (10,000-gallon) run tank
d. Minimum pumping pressure of 700 to 1000 psig
e. Feed piping should be heat-traced and insulated

The information requested from Schwing America included:

1. Receiving station dimensions and estimated cost (excluding pumps) for storage capacity of 250 tons, including ancillary equipment such as push floor dischargers and conveyors.
2. Models and estimated costs for transfer pumps (including screw feeders and power packs) for moving sludge from receiving to live storage and from live storage to run tank.
3. Live-storage building dimensions and estimated cost (excluding pumps) for storage capacity of 2000 tons, including number and sizes of storage silos, sliding frame dischargers, and conveyors.
4. Model and estimated cost for high-pressure feed pump (including screw feeder and power pack).
5. Size and estimated cost for heat-traced piping.
6. Estimate for field erection cost.

Three additional capabilities requested for the pump systems provided by Schwing America were 1) sludge flow measuring system (SFMS), 2) self-diagnostics/monitoring, and 3) reduction of pulsation. The patented SFMS provides an accurate measurement of the volume of sludge being pumped, filling efficiency, speed of the pump, and the accumulated volume of sludge pumped over time. These pump performance readings can be used to monitor and track the pump's mechanical and hydraulic components, thus allowing early detection of component failure. For example, monitoring can be achieved for the wear of poppet valves, excessive internal oil leakage, and blockages at the pump suction side.

The reduction or elimination of pump pulsation may be a critical factor in gasifier operation, specifically with respect to gas cooling and operation of downstream unit operations. The duration of the pulse will depend upon the sludge pumping rate, with the pulse becoming shorter as the sludge-pumping rate increases. One option for eliminating the pulse is to use two control blocks instead of one to independently control each hydraulic cylinder of the sludge pump. The PLC logic would be modified to achieve this control and to compensate for any change in material cylinder-filling efficiency. Essentially, this approach would function to allow the pressurization stroke to begin on the second material cylinder before the first material cylinder piston has reached the end of its discharge stroke. Just as the first piston reaches the end of its stroke, the discharge poppet valve would open on the second cylinder to allow immediate sludge flow. The piston in the first material cylinder would then have to retract at a faster speed than its discharge stroke to allow filling with sludge and then pressurization. A similar approach is employed with dual discharge grout pumps used in underground tunneling applications.

The major components (and associated sizes and power requirements) that comprise each of the three process areas are presented in Tables 20–22. Two-dimensional drawings of the process area layouts, as provided by Schwing America, are presented in Figures 33–36. The drawings are generic and do not depict an actual layout at the Wabash River site.

Table 20. Receiving Station Equipment and Cost Information

Item	Designation/Size	Number Required
Push-Floor Bunkers	20' L × 9.5' W × 20' H	Two
Screw Feeders	SD350HD	Two
Sludge Pumps	KSP80V(HD)L	Two
Hydraulic Power Units	Model 1100 (200 hp)	Two
Budget Capital Cost	$1,300,000	
Average Annual Maintenance Cost	$2500	
Turnaround for Major Maintenance	One week	
Frequency of Major Repair	Every three years	

Table 21. Live-Storage Equipment and Cost Information

Item	Model/Size	Number Required
Sliding-Frame Silos	23' D × 46' H	Four
Hydraulic Power Units	Model 230 (25 hp)	Four
Extraction Conveyors	2' D × 32' L (20 hp)	Four
Screw Feeders	SD350HD	Two
Sludge Pumps	KSP80V(HD)L	Two
Hydraulic Power Units	Model 1100 (200 hp)	Two
Budget Capital Cost	$2,900,000	
Average Annual Maintenance Cost	$4500	
Turnaround for Major Maintenance	One week	
Frequency of Major Repair	Every two years	

Table 22. High-Pressure Feeding Equipment and Cost Information

Item	Model/Size	Number Required
Sliding Frame Silos	13.5' D × 12' H	One
Extraction Conveyors	2' D × 17' L (20 hp)	One
Screw Feeders	SD350HD	One
Sludge Pumps	KSP80V(HD)L	One
Hydraulic Power Units	Model 1100 (250 hp)	One
Budget Capital Cost	$700,000	
Average Annual Maintenance Cost	$2500	
Turnaround for Major Maintenance	One week	
Frequency of Major Repair	Every three years	

It should be noted that the quotes received by Schwing did not include buildings for the sludge- receiving station bunkers, the live-storage silos, or the run tank and high-pressure pump. Schwing America also provided a single cost for each of three process areas and did not provide a per component cost. The receiving station was comprised of two separate push-floor bunkers, each serviced by screw feeder/pump/power pack combination and was estimated to cost $1,300,000. For the live-storage facility, four 7.0-m (23-ft) diameter by 14.0-m (46-ft) high sliding frame silos will be required for 909 metric tons (1000 short tons) sludge storage capacity.

The silos in the proposed design are the largest manufactured and installed by Schwing. Each silo requires a separate extraction conveyor, but a single twin-screw feeder and pump combination can handle the discharge from two extraction conveyors. The entire live-storage cost was estimated at $2,900,000. For the high-pressure feeding area, a single pump (as requested by Global Energy) was utilized and was served by a single 4.1-m (13.5-ft)-diameter by 3.7-m (12-ft)-high sliding-frame silo (with extraction conveyor). The budget cost for this process area was $700,000.

The installed motor horsepower for the each of three process areas was 400, 580, and 270 hp, respectively, for a maximum power requirement of 938 kW (1250 hp). This is a specific power requirement of 22.5 kW per ton/hour, excluding gas compression power requirements. With gas compression, specific power requirements increases to approximately 26.2 kW per ton/hour assuming a minimum of 200 hp for the compressor motor.

Erection costs for a single 7.0-m (23-ft)-diameter by 14.0-m (46-ft)-high sliding-frame silo were estimated to be about $100,000 for ironworker trades. Installation of sludge-receiving bunkers would cost less. Millwright work for installation of each associated screw conveyor and slide frame is approximately $15,000. Interior coatings for each storage silo range from $50–$60,000, and

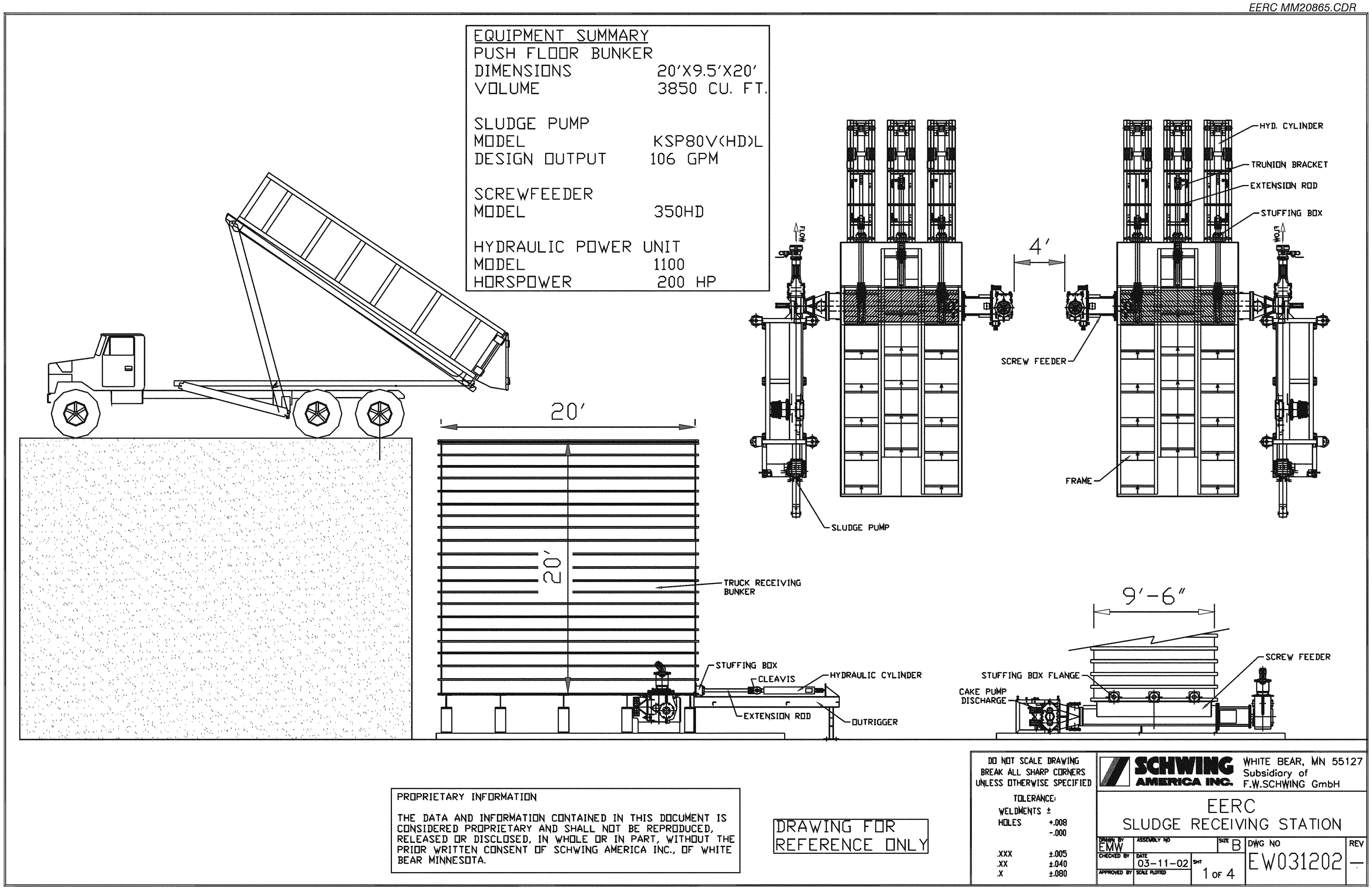


Figure 33. Schematic of sludge-receiving station.

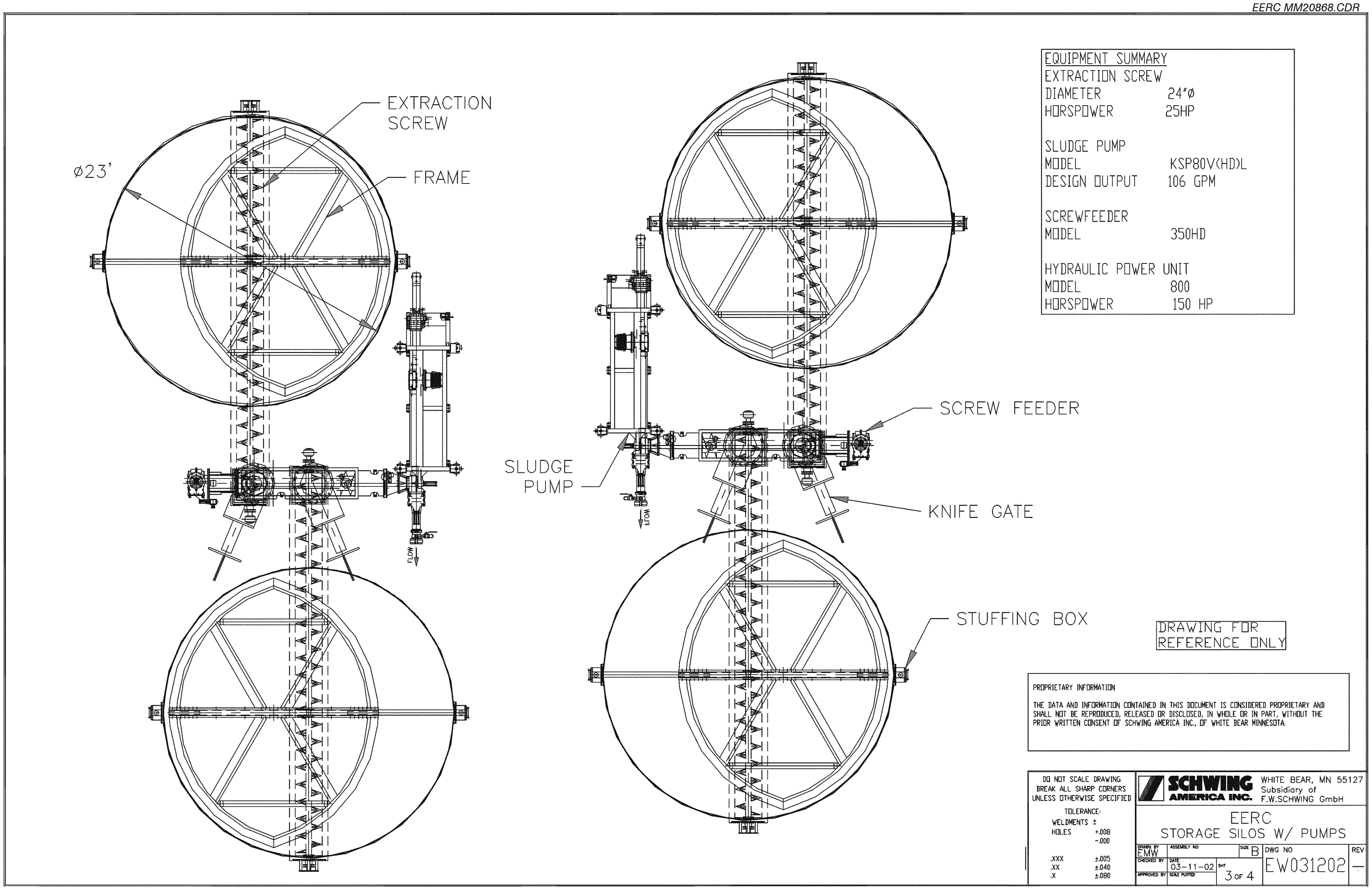


Figure 34. Schematic of live-storage system – top view.

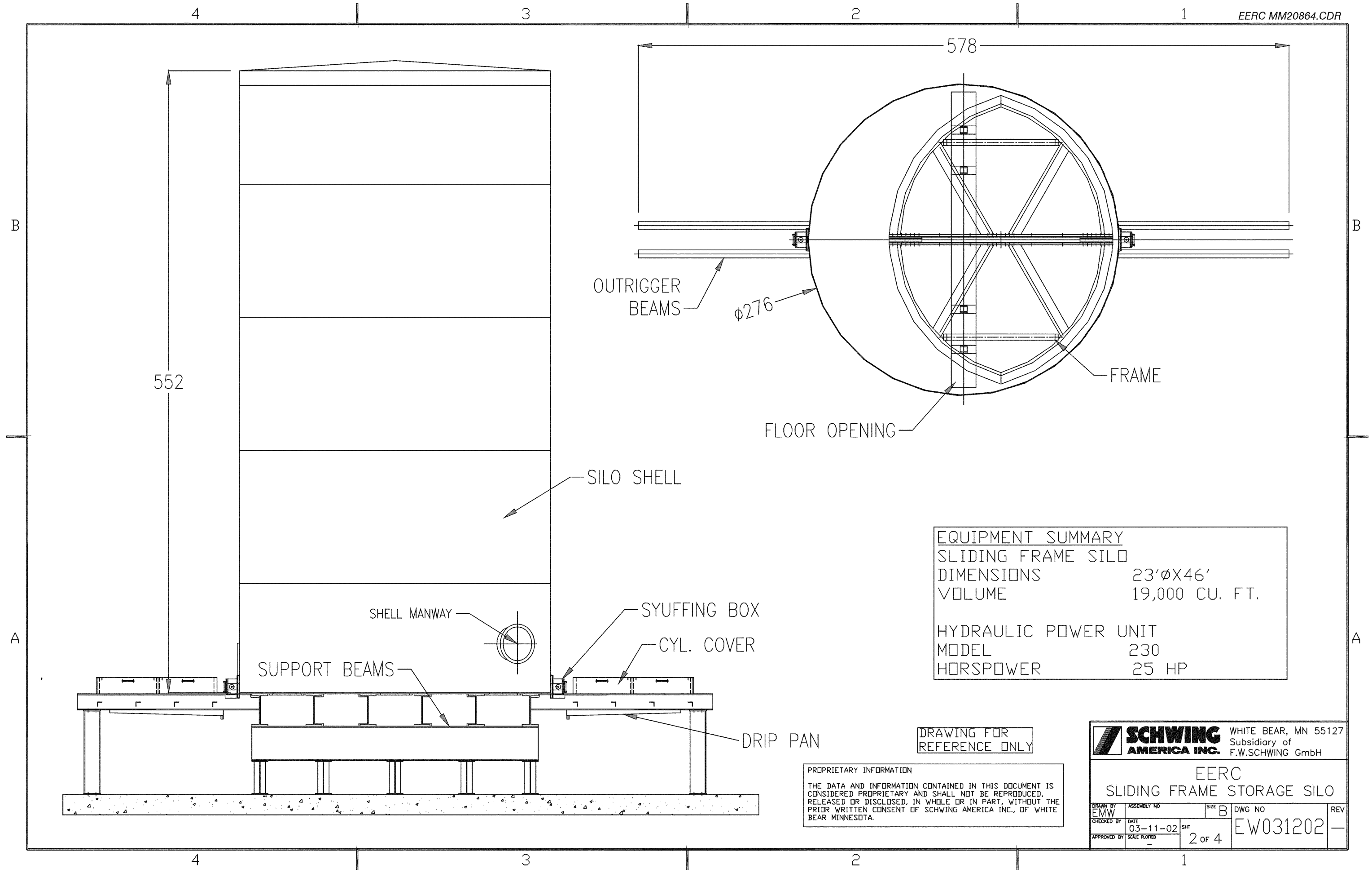
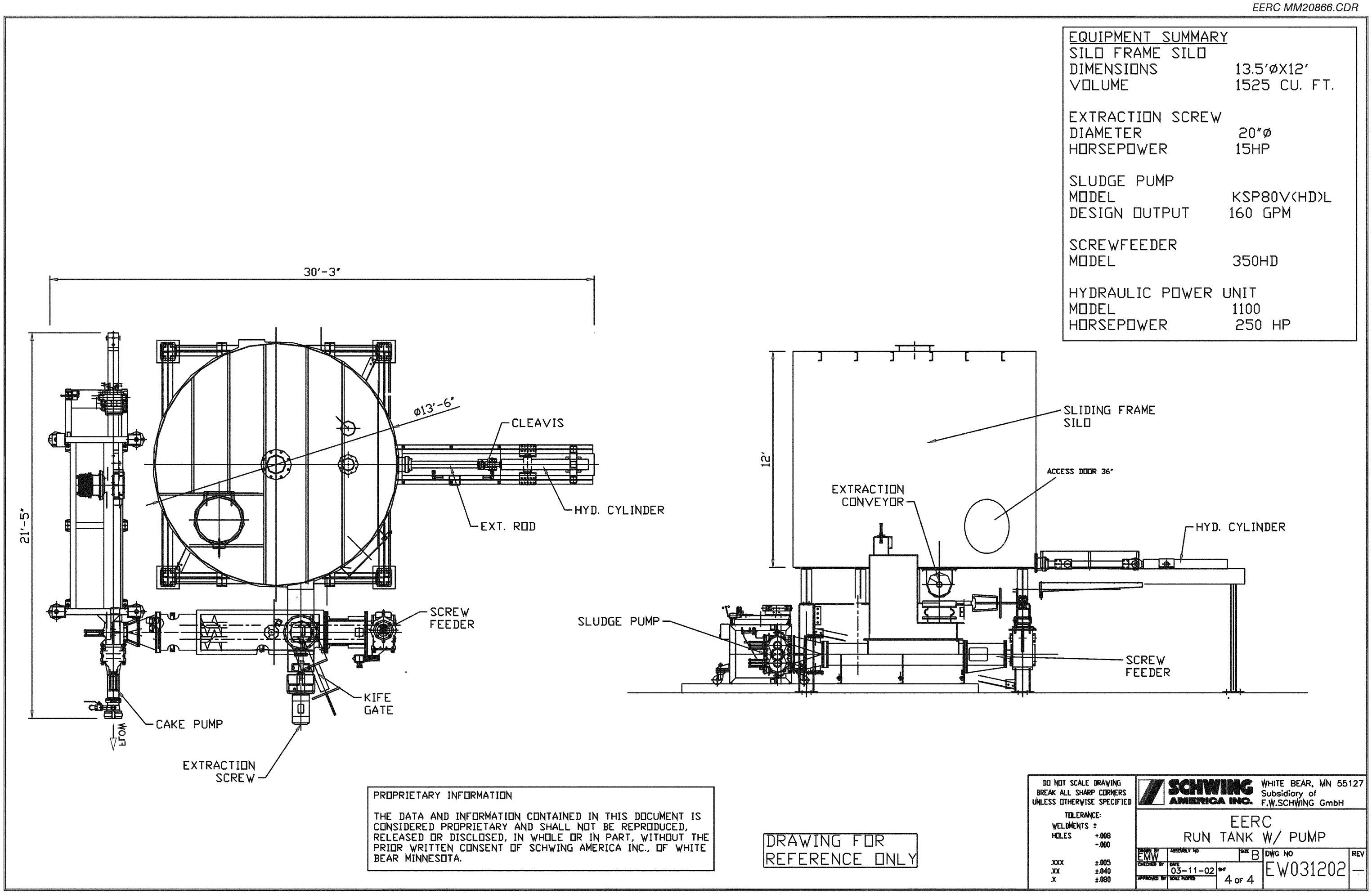


Figure 35. Schematic of live-storage system – side view.



EQUIPMENT SUMMARY

SILO FRAME SILO	
DIMENSIONS	13.5'øX12'
VOLUME	1525 CU. FT.
EXTRACTION SCREW	
DIAMETER	20"ø
HORSEPOWER	15HP
SLUDGE PUMP	
MODEL	KSP80V(HD)L
DESIGN OUTPUT	160 GPM
SCREWFEEDER	
MODEL	350HD
HYDRAULIC POWER UNIT	
MODEL	1100
HORSEPOWER	250 HP

PROPRIETARY INFORMATION

THE DATA AND INFORMATION CONTAINED IN THIS DOCUMENT IS CONSIDERED PROPRIETARY AND SHALL NOT BE REPRODUCED, RELEASED OR DISCLOSED, IN WHOLE OR IN PART, WITHOUT THE PRIOR WRITTEN CONSENT OF SCHWING AMERICA INC., OF WHITE BEAR MINNESOTA.

Figure 36. Schematic of high-pressure feeding system.

exterior coatings would cost about $30,000. Installation of a single pump/screw feeder/power pack system (including hydraulic tubing and wiring) would require about 160 staff-hours. Silos and bunkers would be in the largest reasonable shipping sizes and field-welded on-site. Pumps, power packs, screw feeders, and conveyors would be assembled (and tested) before they arrive on-site and would only require placement and interconnecting service (power, hydraulic, control wiring, water).

Sludge Preheating to Reduce Viscosity

Estimates were prepared for the quantity and cost of steam that would be required to increase the temperature of the sludge. It was assumed that modestly increasing the sludge temperature from 66° to 177°C (150° to 350°F) may produce significant reduction in sludge viscosity and improve atomization. Preheating of the sludge would take place under a pressurized state (presumably in the pipe feeding the gasifier) so that moisture is not released from the sludge. For the estimates, saturated steam at 3.0 MPa (440 psig) was assumed to be available for preheating 909 metric tons (1000 wet tons) per day of sludge at an initial temperature of 16°C (61°F). To preheat to 66°C (150°F), the steam requirement is 141 tons/day; to preheat to 177°C (350°F), the steam requirement is 412 tons/day. Assuming a steam cost of $5/1000 lb steam, the cost of the sludge would be increased $0.328 per million Btu to preheat to 66°C (150°F), and the cost of the sludge would be increased $1.07 per million Btu to preheat to 177°C (350°F). Costs would be lowered if excess heat from the gasifier could be transferred to the sludge through a heat exchanger.

Sludge Nozzle Design and Cost Estimation

Although the pilot-scale testing did not provide an opportunity to address the issues, consideration was given to possible materials for nozzle construction that may have suitable abrasive wear and high-temperature resistance. Referring to Figure 21, it is suggested that options for the nozzle body within the vicinity of the cone could include 310SS and Haynes HR160 alloy. This length of the nozzle body may range from several inches to 0.3 meters (12 inches) in length. The upstream pipe section would be constructed of a less costly material, e.g., 304SS or 316SS, and would be attached to the alloy tip section by welding; HR 160 is TIG and MIG weldable to dissimilar metals. The sacrificial tip section, in essence, would be cut off and replaced after irreparable wear, rather than reconstructing a complete nozzle assembly. The 310SS and HR 160 have Rockwell B hardness values of 85 and 88, respectively. The HR160 is machinable with carbide turning and facing bits and high-speed steel drill bits.

To enhance wear resistance in the instance of using 310SS, the nozzle body tip could be hard-faced with Stoodite 6 by Stoody Products. It is assumed that the air exiting the cone will tend to push the sludge toward the nozzle body and wear on the nozzle body surface, up to the point where the sludge exits the nozzle. At a minimum, the length of the nozzle body containing the cone would be hard-faced. The Stoodite 6 hard-facing comes as a bare rod and is applied with a welder in an argon environment. Stoodite 6 is good to 1150°C (2100°F) in an oxidizing atmosphere and can achieve Rockwell C hardness in the low 40s when two layers are applied. This hard-facing is machinable with carbide tools, thus allowing preparation of a surface finish that will achieve a uniform annular nozzle gap.

The cone of the nozzle would be constructed of HR 160 and would have a threaded connection to allow easy mating with the inner tube carrying the dispersion gas. The nozzle body tip may also include a cooling jacket for thermal protection during loss of sludge flow.

A 10-lb box of Stoodite 6, more than sufficient to prepare several nozzles, costs $474. The 310SS is comparable in price to 316SS tubular or pipe products with 63.5-mm (2.5-inch) Schedule 40 316SS pipe costing approximately $11 per foot. The HR 160 is available directly from Haynes, and a 63.5-mm (2.5-inch) Schedule 40 welded pipe costs about $273 per foot; a 63.5-mm (2.5-inch) round bar costs about $320 per foot.

Ceramics such as boride and alumina silicate products that are sintered may be viable. However, discussions with vendors indicated concerns for the proper material thickness required for structural and thermal integrity. An additional drawback to ceramics is that they are not amenable to field modification, such as addition of dispersion holes in the cone. The ceramic members would have to be initially cast with the desired perforations or other structural features.

An attempt was made to determine the cost of designing and producing a nozzle or nozzles for use in the Wabash River gasifier. As was indicated before, it is presumed that two nozzles would be used, each passing 454 metric tons (500 wet tons) per day of sludge. A spreadsheet, shown in Table 23, was constructed that utilized four variables: engineering design, drafting, parts, and fabrication to estimate cost. The engineering design and drafting costs were assumed to be spread among all nozzles produced. Further, a low-end and high-end estimate was prepared to reflect a possible range in labor effort (i.e., hours for the task) and labor rate ($/hour). In reality, if there are subsequent demonstration phases to this project, most of the engineering design and drafting will not be incurred in the preparation of a commercial nozzle.

Table 23. Cost Estimates for Dual-Fluid Sludge Nozzle

Cost Item	Low-End Cost			High-End Cost		
	Hours	Rate, $/hr	Cost, $	Hours	Rate, $/hr	Cost, $
Engineering	60	75	4500	60	100	6000
Drafting	24	55	1320	24	75	1800
Fabrication (per nozzle)	40	60	2400	60	85	5100
Parts (per nozzle)			1000			2000
Per Nozzle Cost						
One Nozzle			9220			14900
Two Nozzles			6310			11000
Three Nozzles			5340			9700

The per nozzle cost ranged from \$6300 to \$11,000 for producing two nozzles; the total cost for producing two nozzles would then be \$12,600 to \$22,000. This cost component is quite insignificant relative to the capital cost for sludge receiving, storage, and high-pressure feeding and recycle syngas compression.

Economic Analysis of the Sludge-Receiving, Storage, and Feeding System

A detailed capital estimate for implementing the sludge-receiving, storage, and feeding system at the Wabash River Coal Gasification Plant was conducted by Global Energy and was based on process conditions and equipment specifications previously described. The total capital cost was determined to be approximately \$9.7MM within an accuracy of ±10%. The economic analysis for a commercial-scale system processing approximately 1000 wet tons per day is presented in Appendix C.

To determine the economics of implementing the system, process simulation using Gasification Engineering Corporation's (GEC) proprietary computer software was run for petroleum coke and coal operation, with and without municipal sludge. Process information such as heat rate, steam and power output, utility consumption, etc., was determined. An economic analysis using DOE's IGCC Model, Version 3 spreadsheet was then conducted. Greenfield plants were assumed, using reasonable power prices to justify the petroleum coke and coal projects without sludge. Municipal sludge was then introduced for the respective cases to determine the allowable cost (or tipping fee) of the sludge to maintain the same net present value (NPV) for the project. The result shows that a tipping fee of \$12.40 and \$16.70 per wet ton of municipal sludge delivered to the plant site would be required for the petroleum coke and coal projects, respectively. A sensitivity analysis of the power price on the allowable cost of the municipal sludge was also performed.

Drying of Municipal Sewage Sludge

Thermal Drying

During the course of several bench-scale tests, it was observed that municipal sewage sludge produces a hard exterior as it dries from the outside inward. It was presumed that a flowable, spherical, or granular sludge form could be produced that would allow feeding in a manner similar to granular coal, e.g., using a lock hopper. Further evidence of the potential to produce such a material was based on the properties of the 65 wt% solids aged sludge produced by the Water Reclamation District of Chicago. The sample of this material taken from the drying beds had spherical particles and was not sticky. The freeze–thaw cycle during treatment of this sludge made it soil-like in consistency.

Consequently, it was hypothesized that a 3-to-1 reduction in sludge volume, that is, increasing the sludge solids content from a starting value of 23 to a final value of 70 wt% would produce a dry, flowable coal-like material. As Schwing America was the North American vendor for VA Tech Escher Wyss fluid-bed sludge-drying systems (58), they were approached to determine the feasibility of converting about 1000 wet tons/day of 23% solids undigested sludge into a 70 wt% solids product. VA Tech, however, indicated anticipated handling difficulties at this solids content. Plants are in operation that produce a 80 wt% solids product and more typically over 90 wt% solids.

Three drying lines would probably be required, although larger capacities have been achieved in two lines. These plants typically process digested sludge, but this would not eliminate the use of undigested sludge.

For a plant processing municipal sludge to 90% dry solids with three lines, the total capital cost would be approximately $16.5 to 20 million depending on how much wet cake and dry granulate storage would be needed. This gives operating flexibility but adds substantially to the cost. The price includes the dryers, coolers, all basic auxiliary equipment, and controls but does not include the system for supplying the drying energy (can be thermal oil system, steam, etc.).

The thermal energy delivered to the dryers, operating at 100% capacity, would be approximately 81.9 million kJ/hr (77.3 million Btu/hr), assuming 20°C (68°F) ambient conditions. A thermal efficiency of 92% can be reached depending on the heating system, with normal heat recovery. The electrical energy requirement would typically be in range of 1800 to 1950 kW (running all three lines at capacity). For sludge cooling (heat removal), approx. 21300 kW (72.7 million Btu/hr) is required. The capital cost and energy requirements would be lower for product with lower dry solids content.

Nonthermal Drying

A unique, more recent development that could be applied to municipal sewage sludge is the pulverizing air dryer (PAD), a patented, nonthermal drying process (59). Originally developed for drying agricultural products, this process has been applied to food waste, coal fines, manure, municipal sludge, mining ores, and pulp and paper sludge with moisture contents up to 85 wt%. The description of the process appears to be purposely vague to protect proprietary technology, but in essence, the wet material is fed to a high-velocity air stream, reaching speeds of 1280 km/hour (800 miles/hour). These high speeds produce attrition of the material through particle-to-particle collision with control of particle size achieved in a series of “conditioning” chambers. The description refers to centrifugal separation of solids and liquids, implying that moisture is not evaporated to a significant extent. The end product is a granule, with sizes ranging from minus 10 to minus 300 mesh depending upon the product use.

The technology can be brought to a site as trailer-mounted modules with increased processing capacity achieved by adding modules, typically in 10-ton/hour increments. Operating costs are claimed to be significantly less than thermal methods, being approximately $1.50 per ton of water removed compared to $5, $15, and $25 per ton of water removed when using, respectively, coal, natural gas, and electricity as the source of thermal energy. Capital costs for a 200-ton/day system are approximately $1.5 million versus, by Gulftex estimates, $4.5 to $10 million for competing thermal systems.

An intriguing claim of the process with municipal sewage sludge was the ability to make a granular product that could remain in suspension without redissolving. For this process, the sludge was dried to 15 wt% moisture in the PAD and then reduced to less than 200 mesh size. The purpose was to feed the processed sludge through a drip irrigation system. The potential in relation to this project, however, seemed to be to produce a slurried form of municipal sewage sludge at a much higher solids and heating value content relative to direct injection with the dual-fluid nozzles