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TECHNICAL AND ECONOMIC FEASIBILITY OF THERMAL
ENERGY STORAGE

Thermal Energy Storage Application to the
Brick/Ceramic Industry. Final Report

October 1976

Work Performed Under Contract No. EY-76-C-02-2558

Space Division
General Electric Company
Philadelphia, Pennsylvania

ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION

Division of Energy Storage Systems

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THERMAL ENERGY STORAGE APPLICATION

TO THE

BRICK/CERAMIC INDUSTRY

TECHNICAL AND ECONOMIC FEASIBILITY OF THERMAL
ENERGY STORAGE

FINAL REPORT

D.R. GLENN

OCTOBER 1976

CONTRACT NO. EY-76-C-02-2558

SPACE DIVISION

GENERAL ELECTRIC COMPANY

PHILADELPHIA, PENNSYLVANIA

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Donald R. Glenn
Program Manager
Thermal Energy Storage

SECTION 1
PROGRAM OVERVIEW
AND
SUMMARY OF RESULTS

This study was funded by ERDA's Physical Sciences Branch of the Division of Energy Storage as a direct extension of an initial project to study the technical and economic feasibility of thermal energy storage (TES) in the three major consumer markets, namely, the residential, commercial and industrial sectors. A major objective of that work was to identify viable TES applications from which a more concise study could be launched, leading to a conceptual design and in-depth validation of the TES energy impacts. This report documents one such program. The brick/ceramic industries commonly use periodic kilns which by their operating cycle require time-variant energy supply and consequently variable heat rejection. This application was one of the numerous TES opportunities that emerged from the first study, now available from the ERDA Technical Information Center, Oak Ridge, Tennessee, identified as Report No. COO-2558-1.

1.1 PROGRAM OVERVIEW

The program plan was designed to give ERDA an early, detailed assessment of this industry, the process(es) that characterize the manufacturing cycle, and associated energy requirements. This first step was conducted to define the energy conservation potential early in the program to avoid unnecessary expenditures for designs if the potential energy savings were found to be too low. Successful completion of this energy assessment was followed by a conceptual design task that sought to define TES methods which could be implemented in about 3-5 years. This effort developed analytical tools and a data base of process thermal energy dynamics, essential to any TES systems design and development. State-of-the-art reviews of media, containment and heat exchange, and their economic evaluations, were made. A demonstration and test program for the most likely integrated systems design was defined to verify the in-process synthesis of the TES in an actual operating plant setting. Results included definition of test requirements and measurements required to validate energy savings estimates. Finally, a study was conducted to provide guidance for eventual commercialization of a TES device in this industry. This effort explored the customary decision-making paths, communications channels, and several equipment case histories documenting successful market entry. These case histories are illustrative of the path TES systems might take. In addition, government influences and inter-relationships were assessed relative to the industry acceptance of interactions with federal agencies and ERDA particularly. A marketing action plan and schedule was the primary output of this task.

1.2 PROGRAM TEAM

The General Electric Company Space Division - Advanced Energy Programs (GE-AEP) operation led the program and incorporated consultation from brick/ceramic industry representatives. GE recognized that the relevance and technical merit of any TES assessment, design approach, and commercialization program, must be guided by end user inputs. To this end, the Glen-Gary Corporation, Reading, Pennsylvania, currently the third largest U.S. facebrick manufacturer and Hendryx Engineer, Inc., Pittsburgh, Pennsylvania, a recognized consulting engineering firm serving the vitrified clay products and refractories industry, were selected to provide major contributions and guidance to the GE project team. Each organization has implemented aggressive energy conservation practices in its respective business and has published articles in this area.

In order to preserve the "real-world" contributions to the GE program provided by these organizations, their written inputs and industry-unique viewpoints are included in this report. These are presented largely intact in order that the reader may have, firsthand, the opportunity to understand the industry's reaction to conservation, in general, and TES as a conservation alternative. With this excellent support, GE-AEP conducted the energy assessment, TES concept synthesis, and overall program management as specified by the contractual statement of work.

1.3 SIGNIFICANT RESULTS

The three major program tasks as broadly defined in Paragraph 1.1, each produced results from which an overall assessment of TES application validation, design approaches, and commercialization potentials was made. The results of this assessment suggest that implementation of TES can save up to 25 percent of the total energy currently required for periodic kilns within a plant; can pay for itself within 3-5 years depending on local fossil-fuel prices; and find acceptance by plant operators because of the relative ease in integrating the TES unit into existing plant designs. Most importantly, a first generation rock pebble bed TES concept was identified which can be designed and built using current engineering practices and equipment. The market potential study concluded that eventual commercialization can be greatly aided by industry trade associations and communication channels. This should be coupled with federal encouragements in energy allocations, pricing policies, and continued interest in advancing technology R&D in the impacted engineering disciplines to upgrade certain elements of TES functional capabilities for optimization of in-situ (retrofit) situations. A more detailed review of findings, by task, follows:

1.3.1 INDUSTRY ENERGY ASSESSMENT

The industry can be characterized as a large, disaggregated group of companies having strong ties to the small family enterprise. Within recent years, however, a number of large companies emerged (through acquisitions) as the leaders in the several product groupings comprising the vitrified clay and

non-clay refractories manufacturing segments of SIC 32 - Stone, Clay and Glass Products classification, the East North Central and South Atlantic Regions. Natural gas provides about 80% of the needed energy to the kiln-using portions of the SIC 32 industries. Unfortunately, the regional locations of plant concentrations are most susceptible to natural gas curtailments and the highest gas prices making profitability and even survival, a marginal situation. Table 1-1 shows three bar graphs that place the periodic kiln energy consumption in relative perspective with the total U.S. annual energy requirements. In the specific SIC 32 industries of interest, total fossil energy consumption is about one percent of the total U.S. manufacturing demand. Total manufacturing demand is 21 percent of our total nationwide energy use today.

Applying statistical analysis to survey responses from a questionnaire mailing (40% response rate) and correlating with industry data indicates that there are over 3200 periodic kilns in operation in the U.S. These kilns consume 33% of the fossil energy required by brick/ceramic plants. In analyzing periodic kiln thermal performance, over 30% of this energy is lost up the stack during firing. An additional 18-31% (kiln configuration dependent) associated with ware cooling after firing may also be rejected if not recovered for dryer use. Thus, at least 51% of the energy used in periodic kilns is gas-carried and available for recovery by TES in each cycle. For 50 percent energy recovery by TES, an industry-wide energy savings of 16×10^{12} BTU/year could result, which is an average per plant energy savings of 41×10^9 BTU/year.

The average cost impact per plant amounts to an escalating yearly savings starting at \$40,000 in 1975 and increasing to \$213,000 in 1990 based on national price forecasts for fossil fuels and projected industry fossil energy demands over this period. For TES implementation in certain parts of the country using high-priced fuels, these savings could easily be double.

1.3.2 TES CONCEPT DEFINITIONS

A thorough technical analysis of thermal energy flow during periodic kiln operation was performed. A math model was developed to simulate TES input/output conditions, heat exchanger parameters, and heat-containing gas mass and volumetric flow variations over actual firing cycles. Data input for the test cases were based on actual operating data supplied by several plant managers from which a baseline data set was derived. Sensible, latent and hybrid heat storage concepts were researched and sensitivity analyses performed to develop comparative performance evaluations. Bounding each are their limitations to supply heat for combustion air or kiln pre-heating, and drying functions, according to specific demand profiles. The basic system schematic is shown in Figure 1-1. Using standard cost-estimating methods, the major results of this task are shown in Table 1-2. The latent heat system (NaOH) and high temperature liquid sensible heat (NaK) systems offer some advantages in reduced volume associated with their higher energy densities; however, the cost penalties for containment and media raw material costs severely constrain these concepts from a first generation selection. Additional R&D is warranted in the materials areas and heat exchanger designs

TABLE 1-1. 1975 ENERGY REQUIREMENTS FOR STONE, CLAY AND GLASS
SEGMENTS OF SIC 32 AND PERIODIC BRICK/CERAMIC KILN OPERATION

FIGURE 1-1
THERMAL ENERGY STORAGE
IN A
PERIODIC KILN
APPLICATION

CONCEPT	OPER. TEMP. RANGE (ASSUMED)	MILLION BTU'S RECOVERED	DEVICE VOLUME (FT ³)	REFERENCE DIMENSIONS (FT)	DEVICE COST	UNIT COST (\$/BTU)	SAFETY	MAINTENANCE	COMMENTS
1A. BRICK CHECKERWORK	400°F-900°F	171	27,000	40' X 30' X 25' H	\$81,500	\$477	SAFE	LOW	IN PRACTICE OTHER INDUSTRIES
1B. IRON PEBBLE BED	400°F-900°F	171	15,000	30' X 30' X 16 1/2' H	\$630,000	\$3684	SAFE	LOW	SCRAP IRON CHEAPER IF OK
1C. ROCK PEBBLE BED	400°F-900°F	171	26,000	50' X 50' X 10' H	\$68,000	\$397	SAFE	LOW	HIGH H_2 GIVES HIGH ENERGY RECOVERY
2. $NaOH/H_2O$	550°F-800°F	162	26,000	22' RAD. X 17' H	\$177,000	\$1092	EXOTHERM & CORROSION FROM WATER	HIGH	STAINLESS DRUM WOULD INCREASE COST GREATLY
3A. IRON CHECKERWORK IN NaK-78 BATH	400°F-1100°F	157	11,000	12' RAD. X 25' H	\$1,200,000	\$7668	HAZARD	HIGH	HIGH COST AND HAZARD
3B. IRON CHECKERWORK IN NaK-70 POOL	400°F-1100°F	157	12,500	12 1/2' RAD. X 25' H	\$1,005,000	\$6422	HAZARD	HIGH	HIGH COST AND HAZARD
4. IRON CHECKERWORK IN DOWTHERM 6 POOL	400°F-650°F	217	51,000	46' DIA. SPHERE	\$2,236,000	\$10,304	HAZARD	HIGH	HIGH COST AND HAZARD

TABLE 1-2 COMPARISON OF TES CONCEPTS

to upgrade performance and corrosion protection systems for the more attractive liquid metals and salts. The sensible heat TES and specifically the rock pebble bed configuration, is the preferred concept both from a cost criteria and practicality of applied engineering familiarity. Further, the development of pebble-bed heat storage has near term spin-off applicability to other high temperature liquid and/or gas heat transmission processes including advanced solar energy systems. The installation, containment, and component trains use basic off-the-shelf equipment and construction methods that are easily accommodated in most industrial settings. Safety and OSHA impacts are inconsequential compared to other prevalent regulations already met within a plant that contains high temperature combustion-driven systems. The demonstration program definition for this application is straight-forward and specifies instrumentation and test functions compatible with common industry performance evaluation systems used for kilns. This should illustrate to Plant Managers the similarity of the TES with their present operations and concurrently validate the TES impacts projected within the analysis.

1.3.3 TES COMMERCIALIZATION

The challenge of successfully commercializing any TES device was analyzed considering three major aspects: 1) the industry's characteristics, 2) recognition and implementation of process and equipment changes, and 3) the actions and interactions of government (ERDA) and industry.

Brick and other clay products are among the oldest manufactured items in the world and employ a process train not very different from the first primitive mixing, molding and firing methods. The industry has made studies in automating the manufacturing process, but much of the production limiting functions are difficult to change, such as the time for drying and firing which constitute between 70% and 80% of the total process time. Key sensitivities affecting profitability are fuel and labor costs. Raw materials, basic mixing and handling techniques are negligible adders to production costs compared to labor and energy. Transportation costs become important if the market served is more than a few hundred miles from the plant. Thus, close proximity of plant and user is mandatory to realize reasonable profits.

Fuel costs are currently a very volatile element in the financial equation. The study has concluded that to maintain projected brick/ceramic industry growth rates to 1990 under an assumption of constant natural gas availability will require as much as a factor of 3 increase in oil and coal use as alternatives. To implement this changeover will require significant capital expenditures on the part of the industry. This investment could equally well be spent for energy conservation/recovery devices such as TES, if these become economically viable alternatives.

Being a very conservative and de-centralized industry, change comes slowly and returns on investments must allow short payback periods for capital equipment. Most plant owners retain management responsibilities and make the investment decisions.

Recommended Marketing Actions

The successful commercialization of thermal energy storage equipment for the brick/ceramic industry will depend primarily upon the following factors:

- a. Demonstration of a practical process through R&D and a pilot plant program.
- b. Creation of a TES test capability within the government's industrial energy conservation research and development center (possibly at NASA-Lewis Research Center) to lead in development, pilot operation, and communications of technical information to prospective users of TES, and for on-going support in the development of commercial operation of TES by users.
- c. Energetic communication of the capabilities of TES and the benefits to be derived from the use of TES to the operation and financial management of companies in the brick/ceramic industry.
- d. Creation of incentives for the use of TES energy conservation systems through the energy policies of government, and its subordinate energy agencies. Specific areas might include taxation, legislation, and regulations covering fuel cost and availability to users of TES.

These actions, charted in Figure 1-2, are predicated on successfully completing the first demonstration of TES feasibility and the authorization of a pilot plant program.

These, then, are the major resultants of the detailed study of TES applications to the brick/ceramic industry's periodic kiln operations. To be complete, it should be noted that periodic kilns are also employed by the metals industries for heat treating aluminum and steel, as well as other high temperature materials conditioning as is practiced in the glass, concrete and abrasives industries. This report substantiates the credibility of this application and the practicality of developing a first-generation TES configuration using current engineering practices. Most importantly, because the brick/ceramic industry would be particularly restricted by natural gas curtailments, ERDA can achieve an early industrial energy conservation posture by prioritizing this effort to demonstrate that practical technical capability can be applied now.

1.4 STRUCTURE OF THE FINAL REPORT

The detailed program study results are presented in the four sections that follow. Section 2 - Industry Energy Assessment - provides a look at the impacted industry from a national and regional perspective through analysis of periodic kiln energy uses and operation. Details of the industry survey, conducted as part of this effort, and the correlation to overall energy apportionments is also included. Energy impacts relating to TES implementation within the process stream are assessed, technically and economically for the period of 1975 to 1990.

COMMERCIALIZATION OF INDUSTRIAL TES SYSTEMS

ACTION PLAN AND SCHEDULE

FIGURE 1-2. SCHEDULE OF INTEGRATED ACTION

Section 3 - TES Concept Definition - reports on the thermal analysis, simulation capability, and analytical results attained based on a reference kiln configuration chosen to exemplify the technical approach required for TES design. An evaluation of key sensitivities is also included showing the effects of heat content of stack gas, heat exchanger coefficients, and TES capacity (equivalent media mass) on recovery potentials. Finally, several system concepts are developed and evaluated using both sensible and latent heat stores with specified media dynamic response to real-time input/output criteria. A selected approach (pebble-bed) is defined and a design and demonstration program identified with tasks and schedules included.

Section 4 - a TES Commercialization Study - is the report on the TES commercialization challenge for this industry. The study was conducted by Hendryx Engineers, Inc. (under a subcontract to GE), a plant/process/equipment consulting engineering firm exclusively serving the subject industry. Their report, therefore, represents the industry's own view of how it functions and the decision paths it follows in accepting new and modified equipment within its plants and processes. This section provides accurate insight into the several operating philosophies, financial and technical strategies used, and conservative practices characterizing the companies. Several case histories of new capabilities, added as a result of technical advances, are extensively discussed as examples of the obstacles and breakthroughs that have occurred in recent years.

Section 5 - Demonstration Program - discusses the proposed TES demonstration and a means for conducting the design, test and evaluations, using an in-process full scale periodic kiln in an operating plant of the Glen-Gery Corporation, third largest facebrick manufacturer in the U.S. Layouts, schedules, and task definitions of the demonstration program are defined along with program management functions designed to maximize TES publicity and progress both to the procuring agency and the industry.

Section 6 - Appendices - provides technical backup materials, survey details and data substantiating the directions taken.

SECTION 2

INDUSTRY ENERGY ASSESSMENT

This section reviews the kiln-using industry segments, and develops an overall prognosis for TES implementation, based on an assessment of industry-wide energy requirements.

The plant-level process designs, equipment, and energy utilization patterns are presented along with the segment of operations affecting incorporation of TES into the production scheme. Results indicate that energy conservation practices vary with gas availability and level of energy use sensitivity by local management. This varies from no heat recovery to using kiln-cooling gases in the drying function. Attention to combustion efficiency is similarly dependent on management interest in regular maintenance checks on burner operation and the air-fuel ratio (frequently needing calibration). The study has concluded that the need for modern beehive kilns will continue. Even though absolute determination of present or future quantities is difficult to define, the responses to a plant survey indicate that about 15% of current production is provided by periodic kilns.

The regional and national views of the kiln-using SIC 32 industrial components were analyzed. Their historic energy use and market production statistics formed the basis for forecasting energy needs required to match expected market demands into the last decade of this century. The effects of fuel switching, price, and curtailments were studied and, based on present trends, these factors have severely affected this industry's outlook and basic health. Current energy allocations (particularly natural gas) have resulted in a segmented impact according to plant locations relative to fuel producing areas, specific choices of natural gas utility serving an area, and competition for allocated supplies. Due to these factors, plants in one area may be currently free of gas supply problems while "next door" his competition is 50% curtailed. These factors have led to an energy climate in the industry which is particularly receptive to energy conservation measures such as TES.

Overall, SIC 32 industries have exhibited inconsistent patterns of growth as is seen below in Table 2-1. Examination of Census of Manufacturers data (Figure 2-1) reveals that 11% of all fossil fuels consumed by manufacturing industries are focused into the SIC 32 group. Of the total SIC 32 energy usage 14.1% or 1.2 quadrillion BTU's are expended by the larger kiln-using industries. The Middle Atlantic and East North Central Census Regions contain the largest concentrations of plants. For kiln firing, 88% of the fossil fuel demand was met using natural gas in 1972. However, over the last three years, an annual decrease of about 2% in natural gas consumption has occurred resulting from curtailments with no proportionate increase in other fuel usage to make up the supply deficiency. The decrease in number of establishments noted in Table 2-1, indicates business failures in several SIC categories which in part, explains the situation. Figure 2-2 describes these industries as they are scoped by the Department of Commerce's SIC definitions. Other factors involved include the generally poor business picture associated with the economy downturn, tightness of money, and delays in capital improvements by industry. The brick/ceramic/refractory industries are faithful replicates of overall national

MAJOR GROUPS

20	FOOD AND KINDRED PRODUCTS	8
21	TOBACCO MANUFACTURERS	<<1
22	TEXTILE MILL PRODUCTS	2
23	APPAREL AND OTHER TEXTILE PRODUCTS	<<1
24	LUMBER AND WOOD PRODUCTS	2
25	FURNITURE AND FIXTURES	<<1
26	PAPER AND ALLIED PRODUCTS	11
27	PRINTING AND PUBLISHING	21
28	CHEMICALS AND ALLIED PRODUCTS	21
29	PETROLEUM AND COAL PRODUCTS	13
30	RUBBER AND MISC. PLASTICS PRODUCTS	2
31	LEATHER AND LEATHER PRODUCTS	<1
32	STONE, CLAY, AND GLASS PRODUCTS	11
33	PRIMARY METAL INDUSTRIES	18
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36	ELECTRIC AND ELECTRONIC EQUIPMENT	2
37	TRANSPORTATION EQUIPMENT	3
38	INSTRUMENTS AND RELATED PRODUCTS	<1
39	MISC. MANUFACTURING INDUSTRIES	<1

STONE, CLAY AND GLASS PRODUCTS

321	FLAT GLASS
322	GLASS AND GLASSWARE, PRESSED OR BLOWN
323	GLASS PRODUCTS, MADE OF PURCHASED GLASS
324	CEMENT, HYDRAULIC
325	STRUCTURAL CLAY PRODUCTS
326	POTTERY AND RELATED PRODUCTS
327	CONCRETE, GYPSUM, AND PLASTER PRODUCTS
328	CUT STONE AND STONE PRODUCTS
329	ABRASIVE, ASBESTOS, AND MISCELLANEOUS NONMETALLIC MINERAL PRODUCTS

1972

	VALUE OF PRODUCTS		FOSSIL ENERGY CONSUMPTION	
	% OF TOTAL	% OF SIC 32	% OF TOTAL	% OF SIC 32
sic 32	2.9	100	11	100
321		4		5
322		16		16
323		6		<1
324		8		35
325		6		11
326		4		2
327		36		20
328		<1		<1
329		19		10

FIGURE 2-1. PERSPECTIVE OF SIC 32-STONE, CLAY AND GLASS INDUSTRIES

325 STRUCTURAL CLAY PRODUCTS

- 3251 Brick and Structural Clay Tile.**—Establishments primarily engaged in manufacturing brick and structural clay tile. Establishments primarily engaged in manufacturing clay firebrick are classified in industry 3255, nonclay firebrick in industry 3297, sand lime brick in industry 3299, and glass brick in industry 3229.
- 3253 Ceramic Wall and Floor Tile.**—Establishments primarily engaged in manufacturing ceramic wall and floor tile. Establishments primarily engaged in manufacturing structural clay tile are classified in industry 3251, and drain tile in industry 3259.
- 3255 Clay Refractories.**—Establishments primarily engaged in manufacturing clay firebrick and other heat-resisting clay products. Establishments primarily engaged in manufacturing nonclay refractories, as well as all graphite refractories whether of carbon bond or ceramic bond, are classified in industry 3297.
- 3259 Structural Clay Products, Not Elsewhere Classified.**—Establishments primarily engaged in manufacturing clay sewer pipe and structural clay products not elsewhere classified.

326 POTTERY AND RELATED PRODUCTS

- 3261 Vitreous China Plumbing Fixtures and China and Earthenware Fittings and Bathroom Accessories.**—Establishments primarily engaged in manufacturing china plumbing fixtures and china and earthenware fittings and bathroom accessories.
- 3262 Vitreous China Table and Kitchen Articles.**—Establishments primarily engaged in manufacturing vitreous china table and kitchen articles for use in households and in hotels, restaurants, and other commercial institutions for preparing, serving, or storing food or drink. Establishments primarily engaged in manufacturing fine (semivitreous) types of earthenware (whiteware) table and kitchen articles are classified in industry 3263.
- 3263 Fine Earthenware (Whiteware) Table and Kitchen Articles.**—Establishments primarily engaged in manufacturing fine (semivitreous) types of earthenware table and kitchen articles for preparing, serving, or storing food or drink. Establishments primarily engaged in manufacturing vitreous china table and kitchen articles are classified in industry 3262.
- 3264 Porcelain Electrical Supplies.**—Establishments primarily engaged in manufacturing porcelain electrical insulators, molded porcelain parts for electrical devices, spark plug and steatitic porcelain, and other electrical supplies from clay and other ceramic materials.
- 3269 Pottery Products, Not Elsewhere Classified.**—Establishments primarily engaged in firing and decorating white china and earthenware for the trade and manufacturing art and ornamental pottery, industrial and laboratory pottery, stoneware and coarse earthenware table and kitchen articles, unglazed red earthenware florists' articles, and other pottery products, not elsewhere classified.

329 ABRASIVE, ASBESTOS, AND MISCELLANEOUS NONMETALLIC MINERAL PRODUCTS

- 3291 Abrasive Products.**—Establishments primarily engaged in manufacturing abrasive grinding wheels of natural or synthetic materials and other abrasive products. The cutting of grindstones, pulpstones, and wheelstones at the quarry is classified in mining industries.
- 3292 Asbestos Products.**—Establishments primarily engaged in manufacturing asbestos textiles, asbestos building materials, except asbestos paper (industry 2681), insulating materials for covering boilers and pipes, and other commodities composed wholly or chiefly of asbestos. Establishments primarily engaged in manufacturing gaskets and steam and other packing are classified in industry 3293.
- 3293 Gaskets, Packing, and Sealing Devices.**—Establishments primarily engaged in manufacturing gaskets, gasketing materials, compression packings, molded packings, oil seals, and mechanical seals. Included are gaskets, packing, and sealing devices made of leather, rubber, metal, asbestos, and plastics.
- 3295 Minerals and Earths, Ground or Otherwise Treated.**—Establishments operating without a mine or quarry and primarily engaged in the crushing, grinding, pulverizing, or otherwise preparing clay, ceramic, and refractory minerals; barite; and miscellaneous nonmetallic minerals, except fuels. These minerals are the crude products mined by establishments of SIC groups 145 and 149 and industry 1472. Also included are establishments primarily crushing slag and preparing roofing granules. The beneficiation or preparation of other minerals and metallic ores, and the cleaning and grading of coal, are classified in the mining industries, whether or not the operation is associated with a mine.
- 3296 Mineral Wool.**—Establishments primarily engaged in manufacturing mineral wool and mineral wool insulation products made of such siliceous materials as rock, slag, and glass, or combinations thereof. Establishments primarily engaged in manufacturing asbestos insulation products are classified in industry 3292, and textile glass fibers in industry 3229.
- 3297 Nonclay Refractories.**—Establishments primarily engaged in manufacturing refractories and crucibles made of materials other than clay. This industry also includes establishments primarily engaged in manufacturing all graphite refractories, whether of carbon bond or ceramic bond. Establishments primarily engaged in manufacturing clay refractories are classified in industry 3255.
- 3299 Nonmetallic Mineral Products, Not Elsewhere Classified.**—Establishments primarily engaged in the factory production of statuary and art goods made of plaster of paris and papier mache, and in manufacturing sand lime products and other nonmetallic mineral products not elsewhere classified.

FIGURE 2-2. DEFINITION OF SIC 325, 326 & 329 INDUSTRIES

SIC	INDUSTRY SEGMENT	% CHANGE: 1967-72		SIC 32 in 1972	
		GROWTH (VALUE ADDED)	# OF ESTABLISHMENTS	% OF SIC 32 VALUE ADDED	% OF SIC 32 ENERGY
3251	Brick & Structural Tile	34	-14	2.7	6.3
3253	Ceramic Wall and Floor Tile	6	4	0.9	0.5
3255	Clay Refractories	34	8	1.6	2.1
3259	Structural Clay Products	16	-17	1	2
326	Pottery and Related Products	43	43	4.8	2
3297	Non-Clay Refractories	20	-3	1.5	1.2
				11.5	14.1

TABLE 2-1. SIC 32 INDUSTRY CHANGE: 1967-1972

and regional business trends. Construction, primary metals, and mineral industries are the largest customers of these SIC 32 groups, and are indicator industries of economic health. On the regional level, the impact is further iterated as shown in Table 2-2 for SIC 3251. Pennsylvania (in Northeast Region) and Ohio (part of North Central region), and North Carolina (in the South region), together account for about 25% of the employment in this industry. As the table shows, employment in these areas has been severely impacted by the decreasing natural gas supply and declining economy situations. Similar findings are applicable to the other impacted SIC 32 industry groups.

The energy conservation options available at the plant level for the large fuel consuming process functions of drying and firing include improving combustion efficiency, heat transfer, and instituting heat recovery schemes. As a result of numerous survey responses and personal interviews, it is clear that many plants are not implementing even basic maintenance procedures to assure burner operation at optimum air/fuel ratios (product sensitive) or direct recovery of cooling gases, both offering substantial energy savings (payoffs) for a minimum investment. Survey respondents having multiple periodic kiln installations are not adjusting burn cycles for heat recovery, but rather to a required daily (or weekly) production rate. In this environment,

REGION	NUMBER OF EMPLOYEES (1000)		$\Delta\%$	1972 % OF TOTAL
	1967	1972		
Northeast	3.6	2.7	-25	11
North Central	6.7	5.5	-18	23
South	15	13.5	-10	56
West	2.1	2.3	10	10

TABLE 2-2. REGIONAL EMPLOYMENT - SIC 3251, BRICK & STRUCTURAL CLAY TILE

TES is a welcome capability which would allow the present operating plans to continue with the potential for heat recovery. Because the plant mix of kilns and dryers is usually diversified, a generalized conservation approach having broad application and impact is not meaningful. However, in a general sense three areas have been defined where TES can contribute to fuel savings. These are: (1) preheat of combustion air, (2) preheat kilns at the initiation of the firing cycle, and (3) supply hot gas for drying greenware (moisture-laden ware). The energy savings are a function of store temperature and TES capacity as well as the load combination from these three alternatives being supplied from the TES. Drying demands constitute about 25% of the total energy used in the plant, with the remainder required for firing. Preheated combustion air at about 500°F can save 10% of the fuel required for the firing cycle. In the direct application of heat to preheat the kilns to 300°F, another 10-12% savings is available. Thus, an infinite storage capability of 500°F could effect up to a 45% reduction in the fuel requirements of periodic kilns and associated dryers.

To determine the specific savings available through TES application the complete refractory products industry was investigated. The following sections discuss the manufacturing sequence and associated energy requirements for typical kiln operations.

2.1 PLANT PROCESS VARIATIONS

The end user of periodic kilns and batch dryers produces a variety of products that differ in shape, weight, moisture content, type of composition, and mechanical strength. The process requirements must account for these conditions as well as provide for finishing that can include glazing, colors and flashing. This section shows the fundamental process flows, plant layouts,

and details the energy budgets associated with periodic kilns. Relationships are analyzed to define TES capacity and integration requirements as a function of envisioned heat recovery components in present kiln operations.

2.1.1 PROCESS RELATIONSHIPS

The family of refractory products has two common ingredients, clay and water. Depending on the particular end item, additives may be included to provide high temperature resistance, porosity, acid-resistance, surface finish and erosion or spalling resistance. The fundamental process flow is as shown in Figure 2.1-1. For purposes of this study, the drying and firing functions are of primary interest, since thermal energy demands are basic only to these process steps.

The drying and firing stages of manufacture are generally located in close proximity to take advantage of normal material flows and handling equipment for the final form of the product. After set-up on kiln cars following the molding, extrusion and final trim operations, no further direct handling occurs until after the cars exit the kiln. Therefore, once set as greenware, the products are usually transferred between plant equipment using intermediary aids such as refractory-topped cars or pallets. This is for modern tunnel or shuttle kilns. Some older beehive kilns require manual loading and handling.

2.1.2 EQUIPMENT LAYOUTS

The evolution of the refractory industry began with small, family-owned businesses. Growth and plant expansions did not always result in optimum placement of equipment for material handling and processing steps. Modern plants usually separate the process into several sections: 1) raw materials storage, 2) mixing, blending and production forming, 3) final setting and drying, 4) kiln operations, and 5) preparations for shipment (including final inspection).

In practice, equipment layouts are determined by several factors, including:

1. Available space.
2. Compatibility of process equipment.
3. Plant building configuration.
4. Expansion plans
5. Personnel work stations.

Figure 2.1-2 shows a sample layout and material flow, although there are numerous alternative physical arrangements, representative directions of material flow are as shown.

FIGURE 2.1-1 BASIC FLOW FOR REFRACTORY PRODUCTS

FIGURE 2.1-2. PLAN VIEW-REFRACTORY PLANT

2.1.2.1 Raw Materials Store, Mixing and Blending

In this step clay, shale, silica, and oxides are processed into a very finely ground powdery form. Dry mixing occurs after which the materials needed are blended prior to water addition. These steps are usually housed separate from other functions due to the dusty environment caused by the handling requirements of the raw materials. Once water is added, cohesive bonds are formed. Blending equipment creates a homogenous mix of ingredients with the needed properties for forming.

The prepared mix is fed into one of several machines for forming. Forming methods include casting (or molding pressing), and extrusion. Product formulations have been steadily improved to reduce the amounts of moisture required in these steps to result in self-supporting products capable of being handled without damage. After forming, color, surface texture or finish for brick, and final trim or cutting completes the preparations for the final operations - drying and firing.

2.1.2.2 Setting, Staging and Drying

These process steps are usually in-line functions. Formed greenware are either manually or automatically set on the kiln cars or dryer racks. In many industries where larger or heavier items are produced, the ware is placed directly on the kiln car for routing to the dryer to eliminate double handling. This area is adjacent to the drying and firing equipment and is usually connected by rails or conveyers to transfer the greenware to the dryers. Positioning the greenware is very important to assure that the surfaces and shapes to be fired are exposed to even heating and cooling thermals in the dryers and kilns to prevent unsymmetrical shrinkage during drying and firing of the ware.

Drying removes much of the shrinkage water. Staging of the greenware into and from the dryers allows matching the ware firing requirements to the kiln operating cycles, in the case of periodic kilns. Greenware must be dried to avoid surface dehydration while the inner mass is moist. Therefore, staging of dried and wet greenware to the dryer operation is required. Once dried, the ware can sit many days before being fired in the kiln, absorbing only hygroscopic moisture which is easily removed as vapor in the kiln's initial heat up period.

2.1.2.3 Kiln Operations

Within the refractory industry, the largest commitment of space and support operations is allocated to dryers and kilns. A typical flow for the dryer and kiln operations is shown in Figure 2.1-3. Close proximity of kilns and dryers allows centralized dual feed and thermal monitoring stations as well as shorter ducting lengths interconnecting the kiln(s) to the dryers, where recovery of cooling gases for kiln preheating or drying is practiced.

FIGURE 2.1-3. KILN-DRYER AREA PLAN VIEW

Over the years many plants have modernized their equipment and facilities. The individual modifications are numerous and diverse; however, one generalization is apparent. Older facilities are not generally replaced with new equipment. Therefore, older kilns, such as the beehive-type built during the late 1800's and well into this century still stand and are easily activated when special products or plant capacity demands their use. A fairly typical evolutionary layout is shown in Figure 2.1-4 for a facebrick plant. Clearly seen is the old portion of the plant where the 7 beehives are located in conjunction with the more recent plant additions housing the tunnel and batch-dryers and tunnel kilns. Note the "natural" linkages of each function with respect to process continuity.

2.1.3 COOLING AND PACKAGING

Cooling from the maturing temperatures to about 600°F or less occurs within the kiln at a controlled descent. As used here, cooling is from the ware's kiln exiting temperature to a level permitting unloading the kiln cars to package the final products for shipment, or for transfer to inventory areas.

There are many products that comprise the clay refractories group. Common to all are the use of clays and water plus other additives to tailor the product to the requirements of its end use. The pattern of manufacturing process functions varies little from the general description of equipment required and their interactions in a plant layout.

2.2 VARIATIONS IN REFRACTORY PLANT KILN OPERATIONS

The several plants visited during the study represent a wide range of plant sizes and product firing temperatures. An example of these extremes are the Glen-Gery Plant at Shoemakersville, Pa., the third largest brick plant; and Lava Crucible Refractories, in Zelienople, Pa., which produces specialty products for the primary metals industries.

Plant kiln use variations occur to:

- control plant output
- levelize staffing (manpower) needs
- meet changing inventory strategies
- produce diversified product mixes.

Several examples serve to illustrate some of these points:

1. A plant in Ohio comprised entirely of beehive kilns schedules their use such that two kilns are emptied daily to yield a fixed amount of ware output and maintain constant employment levels.

FIGURE 2.1-4. TYPICAL BRICK MANUFACTURING PLANT LAYOUT

2. A large facility in Pennsylvania uses periodic kilns only as a backup capability to their continuous kilns and to manufacture special orders not compatible with continuous kiln operations from a technical and/or economic viewpoint.
3. To compete favorably, smaller companies offer a wider variety of products in small (and large) quantities. Periodic kilns offer greater flexibility for firing curve modifications to adopt to the unique characteristics of each product than is possible with continuous kilns. Similarly, periodic kiln output (hence operations) can be modulated to match variable customer demands.

2.2.1 PERIODIC KILN UTILIZATION AND ENERGY PROFILE(S)

Vitrified clay products are dried, then fired in order to create certain physical/thermal characteristics. To define the areas of greatest potential for integrating TES designs, the basic steps of refractory manufacture associated with dryers and kilns were studied and are described below.

2.2.1.1 Characteristics in Refractory Products Manufacture

There are many factors associated with producing ceramic products according to their particular composition, i.e., tile vs. bricks. The composite curve shown in Figure 2.2-1 represents a nominal temperature profile associated with brick manufacture in a periodic (beehive) kiln. However, the basic functions to be described are equally relevant to fine ceramics, structural clay products, and refractory products. Variations occur in adjusting rates of heat application, holding temperature levels and ultimate maturing temperatures.

In reviewing the Figure 2.2-1 curve, it is important to remember that the shape of the curve is the key factor in developing the needed associations with the TES application. The time axis accounts for inefficiencies of the particular kiln (the heat related to temperizing the kiln liners and structure to the required levels plus losses at a constant "U" value). The temperature axis is determined by the product requirement. Consequently, time compressions or expansions for a given product are mostly related to kiln performance capabilities. This basic firing curve, with specific values for actual kiln operation, was used in the study for analysis (Section 3.0) and energy savings evaluation (Section 2.3). The reference kiln cycle based on this curve is presented in Section 3.2.4.

2.2.1.1.1 Drying

All refractory products contain water as a basic ingredient of the ware composition. This water must be removed during the ware cure cycle. This removal occurs by the heating and humidifying of the surrounding environment to levels and at rates related to the basic structural characteristics of the "green" articles. Drying rates are a function of capillary formations in the mixture, itself a function of the particle sizes of the basic ingredients (from

FIGURE 2.2-1. FUNDAMENTAL KILN FUNCTIONS

1-50 microns or more). Drying involves removal of shrinkage water, physically bound water and chemically bound water.

Moisture transfer of the shrinkage water occurs through the capillaries as applied heat expands the water to drive it out. The maximum rates are determined by the sizes of the capillaries, viscosity of water, and the shrinkage or closing rates of the openings without cracking or deformation. When the ware shrinkage ceases, the evaporation of this water is complete.

Initial drying air is humidity-controlled starting at close to saturation levels to permit even heating of the ware before water removal by evaporation to prevent uneven shrinkage. By depressing the wet-bulb temperature (dehumidifying), water is then carried away at known removal rates corresponding to the rate of water transfer to the ware surface. This drying phase is accomplished by heating the water to $\sim 195^{\circ}\text{F}$ (90°C). If molds are required, as for thin-walled products, drying temperatures proceed to $130\text{--}150^{\circ}\text{F}$ ($55\text{--}65^{\circ}\text{C}$), the ware is removed from the molds, and the temperature raised to the final value for shrinkage completion.

Continued application of heat is required, 1) in heating the ware, and 2) heating the contained water. With shrinkage complete (the capillaries closed) further removals are through diffusion of the entrained water as vapor and/or steam. This phase is characterized by a change in heat consumed for evaporation of the moisture and an increase in the heating up of the greenware. In this phase the temperature is raised to just above steam temperatures or 230°F (110°C). These two drying phases liberate water mainly as liquid and/or vapor.

The chemical constituency of refractory products is a variable dependent on the particular end uses of the ware. During processing chemical reactions between the greenware ingredients and water occur. These reactions result in a resistive portion of physical-chemical combined water in crystal lattices.

This dehydration heating follows the first two drying phases. In this phase the clay loses its plasticity through breakdown of the crystal lattices and release of the water of crystallization. These changes occur at different temperatures for each clay compound. For kaolinite, the most common clay, this breakdown occurs at about 1025°F (550°C) and in anhydrous aluminum-silicate clays at temperatures up to 1470°F (800°C). The transition characteristic is marked by an oxidation of volatiles and a sudden decrease in ware material strength.

2.2.1.1.2 Vitrification (Sintering)

With the completion of the drying phases, the ware materials undergo intensive densification characterized by rapid variation in porosity with temperature rise, Figure 2.2-2. In the figure, the change in temperature between the upper and lower absorption "knees" of the curve represents the sintering range. The "softening point" is the indication of the final (desired) physical state. The difference in temperatures between the "softening point" and the 2% or 5% water absorption points indicates the degree of sintering. Clays are classified with reference to the figure as follows:

FIGURE 2.2-2. SINTERING PROCESS

CLAY CLASSIFICATION (VITRIFIED OR SINTERED STATE)	SINTERING DEFINITION
Nonsintering	Softening Point - 5% Point $\leq 122^{\circ}\text{F}$ (50°C)
Moderately Sintering	Softening Point - 5% Point $\geq 122^{\circ}\text{F}$ (50°C)
Strongly Sintering	Softening Point - 2% Point $\geq 122^{\circ}\text{F}$ (50°C)

In general, the higher the vitrification temperature of the material, the greater the refractoriness, or the ability to sustain high temperature.

2.2.1.1.3 Cooling

After attaining the desired curve temperatures, hence sintered state, the heat input is lowered to just offset thermal losses of the kiln, then the burners are shut-down. During the cooling phase, several critical changes occur in the ware which require control. These changes include crystallization, and the formation of cracks and micro-cracks in the products. The rate of temperature drop (or heat removal) follows a time relationship, defined by the thermal shock resistance capacity of the final product.

2.2.1.2 Characteristics of Kiln Thermal Energy Systems*

Modular kilns have increased energy efficiencies through incorporation of low density insulation such as fiber blankets and modern insulating refractory brick and liners. Kiln thermal loss sources are illustrated in Figure 2.2-3.

FIGURE 2.2-3. KILN HEAT LOSS FUNCTIONS

* Vitrified clay products

The mass comprising the walls and cap accumulate a large amount of heat in the early firing stages. These losses approach zero as the kiln brickwork reaches set temperature. Losses to surroundings increase as the kiln brickwork heats through. These losses account for the design-limited energy efficiency of the kiln, a function of thermal conductivity and heat capacity. Figure 2.2-4 illustrates these losses for several kiln constructions. Lightweight insulating refractory "U" values are 2-3 times below common refractory products. Once thermal equilibrium is established at a point along the firing curve, the losses are constant. Kiln losses are proportionate to the hours for firing. A beehive kiln curve (Figure 2.2-1) which requires 78 hours for firing contrasted to about 30 hours in a shuttle kiln is illustrative of the expected range. The shuttle kiln incorporating modern, low density insulating refractory liners results in a fuel savings of almost 40% for this loss function.

The other losses are associated with heat flow and gas compositional changes during the drying and firing phases. A sample heat balance of the drying and firing cycle represented in Figure 2.2-1 will serve to illustrate the heat input requirements. Figure 2.2-5 shows these drying energy requirements in both the dryer and the kiln for VCP* brick. The VCP brick, as molded or extruded by plastic molding, contains up to 20-24% moisture. To allow multi-row stacking on kiln cars, this moisture content should be no more than 7-9% to achieve the necessary strength to support the setting. This is the usual moisture content of brick entering the kiln where the remaining moisture is removed (to the equilibrium moisture content). This point is indicated by a sharper rise in ware temperature due to the absence of the latent heat change component of bound water evaporation. Remaining heat additions create conditions for physical-chemical reactions associated with curing the ware.

To bring this heat to bear on the ware, a heat exchange must take place between the combustion heat and the ware within the kiln envelope. This process employs the products of combustion and excess air to convect the heat to the ware. Several factors impede the transfer of this heat and must be accounted for. A model of the heat flows within a periodic kiln are shown in Figure 2.2-6.

The energy requirements calculated in Figure 2.2-5 apply to the "ware" only, the other blocks forming the loss functions. Thermal flow rates from combustion products are functions of either the ware process requirement or kiln accumulation time (thermal inertia). The hot gas flow paths are designed to evenly distribute the thermal energy to the ware, as set in the kiln in all three dimensions. In modern kilns, the gas atmosphere is also controlled relative to chemical reactivity with the ware, i.e., reducing, oxidizing or neutral, to develop preferential properties at the elevated maturing temperatures.

* vitrified clay products

HEAT STORAGE IN KILN WALLS AND CROWN

HEAT LOSSES THROUGH WALLS AND CROWN

FIGURE 2.2-4. KILN HEAT LOSSES

EQUIPMENT	FUNCTION	REQUIREMENT
Dryer	<ol style="list-style-type: none"> Heat ware to drying temperature. Evaporate water 	<p>Ware specific heat $\times$ $(T_{\text{Dry}} - T_{\text{Ambient}}) \times$ Wt. (including moisture)</p> <p>980 $\times$ Wt. of water removed.</p>
Kiln	<ol style="list-style-type: none"> Heat ware to remove remaining water. Evaporate water Heat ware to cure temp. 	<p>Ware specific heat $\times$ $(T_{\text{Oxidation}} - T_{\text{Ambient}}) \times$ Wt. (including moisture).</p> <p>980 $\times$ Wt. of remaining water.</p> <p>Ware specific heat $\times$ $(T_{\text{Cure}} - T_{\text{Oxidation}}) \times$ Wt. dry weight.</p>

For the facebrick example, assuming a clay specific heat of .26 and an initial moisture content of 24%, the heat requirements in BTU/lb. product:

Dryer:	Heat 1.24 lb, 70-125°F	39 BTU
	Evaporate 0.13 lb. water	<u>127 BTU</u>
	Total in Dryer	166 BTU
Kiln:	Heat 1.09 lb, 70-1100°F	291 BTU
	Evaporate .09 lb. water	88 BTU
	Heat 1 lb. to cure, 1100-1900°F	<u>208 BTU</u>
	Total in Kiln	587 BTU

FIGURE 2.2-5. WARE HEAT REQUIREMENTS

FIGURE 2.2-6. KILN THERMAL MODEL

Norton (1) presents examples of fuel consumption for several types of periodic kilns. While the data presented does not define the kilns as being insulated, Norton shows that insulation impacts kiln performance in two ways: by reducing losses through the walls and crown (considered constant) and as a direct result, reducing the flue losses since heat input is then proportional to heat lost up the stack. Consequently, since losses through the structure are lower, less input is required for heat make-up, hence, less flue gas losses. He estimates that improvements in thermal efficiency of 50% or greater over uninsulated kilns are realistic. Using the basic heat balance calculations, as in the example above for facebrick for other ware types, kiln thermal efficiencies can be derived based on fuel consumption data sources reported by Whittmore (5). Several examples are shown in Table 2.2-1.

PERIODIC KILN	CURE TEMPERATURE (°F)	ENERGY (BTU/LB. PRODUCT)		KILN EFFICIENCY (%)
		WARE REQUIREMENT*	TOTAL	
1. 32 ft. with IFB liner	2000	626	2100	30
2. 32 ft. with firebrick lining	2000	626	4300	15
3. Periodic with fireclay retorts	1900	600	8500	7
4. Periodic- porcelain	2650	975	43000	2

* Heat balance calculated

TABLE 2.2-1 KILN EFFICIENCIES

As shown in the table (examples 1 and 2 above), the efficiencies of older, uninsulated kilns can be doubled with added insulation, such as insulating fireclay brick (IFB). The losses accounting for the low efficiencies shown are further defined in paragraph 2.2.1.3 below.

Relative to the products being fired, the general heat transfer relationships for sensible heat absorption hold with the exception of a latent heat

input to expel pore water at lower temperatures and the chemically combined water of the particular clay compound under fire at elevated temperatures. Figure 2.2-7 shows the latter (depressed peaks) for several different clay minerals. Kiln heat rates for several refractory products are shown in Table 2.2-2 for a representative range of capacities. The energy consumption variation shown indicates sensitivity to such factors as kiln insulation and burner characteristics shown previously to have significant effects.

2.2.1.3 Energy Profiles

A heat balance for a periodic kiln considers all thermal energy users to bring the ware to maturing temperature. Kiln efficiency is the sum of the above thermal energy components divided by heat value of fuel consumed. Because of kiln design variations, the several categories of thermal energy uses are not a consistent percentage of total energy demand; however, Table 2.2-3 is an estimated set of values based on averages from the available data for uninsulated kilns which was used as a starting point for evaluating TES energy saving potential. Uninsulated kilns are typical of most periodic kilns currently in operation.

HEAT USE CATEGORY	PERCENTAGE OF TOTAL ENERGY REQUIRED	
	RANGE	NOMINAL VALUE
Moisture Removal	0-3	8
Heat in Vapor in Gases	4-7	
Heat Storage in Walls	4-15	14
Heat Storage in Crown	2-4	
Heat through Walls & Crown	3-9	18
Heat through Bottoms & Flues	4-12	
Heat in Dry Flue Gases	20-45	36
Heat of Combustion of Ash	4-10	6
Heat of Combustion of Flue Gases	0-5	
Heat Loss in Cooling Ware*		18

*Ware heat input is 20% with 2% loss due to latent heat exchange in vapor diffusion.

TABLE 2.2-3. UNINSULATED PERIODIC KILN HEAT BUDGET

TEMPERATURE DIFFERENCE

FIGURE 2.2-7. CLAY DIFFERENTIAL THERMAL ANALYSIS CURVES

TABLE 2.2-2. DOWNDRAFT PERIODIC KILN PERFORMANCE

SOURCE	ENERGY (1) PER 1000 BRICKS		CAPACITY SIZE	CYCLE (HRS)	CONFIGURATION (2)
	OIL EQUIV. (GALS.)	10 ⁶ BTU			
Carborundum Co.	37.5	5.2	180,000	114	B (30% of cost)
	62.4	8.7		216	A
	85.5	11.9		216	C
Victor Cushwa & Sons	60	8.4	50,000	48	E, D
	90	12.6		168	C
General Shale Products	76.2	10.6	50,000		C
Acme Brick	25.5	3.5	120,000	68	A, B, D (\$95,000/Kiln)
Norton, Refractories	209.5	29.3	65,000	192	Unknown
	138.1	19.3	32,000	152	"
	126	17.6	60,000	156	"
	142.8	19.9	48,000	132	"
	125	17.5	76,000	110	"
	135.3	18.9	50,000	216	"
Babcock & Wilcox (Ceramic Bulletin, Vol. 46,		17.6	62,000	120	C
		12.4	62,400	112	A, C
Dickson, E.J. "Kiln Designing Advances using Characteristics of Insulating Refractories", Ceramic Bulletin, Vol. 46, No. 12 (1967)		8.8	62,500	79	A, D
		8.6	90,000	104	A, B
		7.5	100,000	96	A, B, D

(1) 1 Gal. Oil = 133 Ft.³ Gas
 = 10.5 lbs. Coal
 = 140 m BTU

(2) Kiln Provisions: A. Insulating Firebrick
 B. Ceramic Fiber Insulation and Thin Walls
 C. Hard Walls
 D. Hi-Velocity Burners
 E. Shuttle Kiln

Kiln efficiency is defined as the sum of the heats of water removal plus cooling heat loss - the heat contained in the ware at the end of the firing cycle. From the above table kiln efficiency for a typical uninsulated kiln is about 26%. To better define the extent of TES applicability, each heat use category must be understood from a current industry perspective and then from an R&D objective. The mechanisms of these heat uses and the form of their ultimate "loss" (gas, radiation, etc.) is important in specifying heat recoveries of interest and the requisite TES hardware designs.

2.2.1.3.1 Moisture and Vapor Removals

The heats required for water removal, as moisture, are at low temperature levels (under 212°F). The clay structure is heated at high humidity followed by a lowering of the humidity to draw off the small amounts of shrinkage water remaining after drying (~5-8% for brick). The moisture being carried away by circulating gases is ultimately wasted to the flue. Additional heats cause the pore water to diffuse as steam at about 300°F for most clays. From the completion of this phase to the next plateau, where the chemically combined water is liberated, the hot gases can contain any of several contaminants, such as the oxidized products of carbon and sulfur. Their presence is a function of the impurities contained in the basic clay mix. Temperatures of reaction for these impurities are shown in Figure 2.2-8. Coupling these temperature ranges to the sample latent

REACTION	REACTION TEMPERATURES	
	°C	°F
$\text{FeS}_2 + \text{O}_2 \rightarrow \text{FeS} + \text{SO}_2$	350-450	660-840
$4\text{FeS} + 7\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3 + 4\text{SO}_2$	500-800	930-1470
$\text{Fe}_2(\text{SO}_4)_3 \rightarrow \text{Fe}_2\text{O}_3 + 3\text{SO}_3$	560-775	1040-1430
$\text{C} + \text{O}_2 \rightarrow \text{CO}_2$	350	660
$\text{S} + \text{O}_2 \rightarrow \text{SO}_2$	250-920	480-1690
$\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$	600-1050	1110-1920
$\text{MgCO}_3 \rightarrow \text{MgO} + \text{CO}_2$	400-900	750-1650
$\text{FeCO}_3 + 3\text{O}_2 \rightarrow \text{Fe}_2\text{O}_3 + 4\text{CO}_2$	800	1470
$\text{CaSO}_4 \rightarrow \text{CaO} + \text{SO}_3$	1250-1300	2280-2370

Source: Norton (1)

FIGURE 2.2-8 BREAKDOWN TEMPERATURES OF CLAY IMPURITIES

heat exchange peaks of Figure 2.2-7, the resulting chemical reactions in the hot carrier gas within the kiln indicate formation of potentially corrosive products involving the contained water and these reaction products. Careful analysis of these phenomena can result in the capability to reclaim the heat in the exhaust gases in bands relatively free of corrosive products such as between the upper temperature peak (latent-heat absorption) and the lower temperature pore water removal reaction. These practical considerations must be addressed in designing the control system for a TES recovery installation to provide maximum energy savings.

2.2.1.3.2 Heat Storage in Kiln Structure

As shown earlier in Figures 2.2-3 and 2.2-4, heat transfer from the hot gases to the kiln internal surfaces account for almost 20% of the total heat input. The heat contained (stored) in the kiln lining materials is not retrievable unless the liners contain flow channels. However, inclusion of flow channels increases the effective "U" value of the structure. To utilize this potential area for heat recovery requires improved insulation designs and gas circulatory patterns to improve gas convected and radiated heat transfer to the ware. One such design is shown in Figure 2.2-9.

2.2.1.3.3 Heat Losses through Kiln Walls and Crown

These losses which account for about 6% of total demand are a constant associated with a thermally "soaked" structure where radiative and convective losses to the surrounding environment occur. Heat transfer follows the same logic as the ware within the kiln during cooling. Figure 2.2-4 showed these losses for a variety of constructions. Insulating firebrick (IFB) is currently used to upgrade periodic kiln efficiency; wall and crown heat loss recovery has not been of interest, thus far, for energy recovery. Several cases of energy impact are shown in Table 2.2-4 for a round downdraft kiln, 32 ft. in diameter with 11 ft. walls, using data from Figure 2.2-4. Combining Wall A with Crown G yields a total loss of 109 mm BTU (817 gallons of oil equivalent). Summing Wall F (2000) with Crown K (2000) shows these losses reduced to 21.8 mm BTU (163 gallons of oil equivalent). With respect to ware energy demand, 109 mm BTU is equivalent to 50% of ware total heat requirements, not an insignificant amount. Presently, this heat is radiated and convected to the plant space, if the kiln is under shelter, or the environment in the case of outdoor operations.

While not the target of this study's objective, it is clear that the use of low density insulating firebrick can materially lower the heat losses in kilns in two ways: by reducing the heat contained within the structure (due to lower density) and by a reduction in heat losses to the exterior environment (due to low thermal conductivity associated with high porosity). In examining the convective and radiation losses, some interesting potentials for recovering this heat can be conceived.

During the firing cycle, the mechanics for transferring heat into the ware (gas-solid) can be used in reverse (solid-gas) by sweeping the walls and crown with a forced draft gas flow contained within a "bubble" envelope, blanket, or

Down Draft Shuttle Kiln Saves 15 to 35% Fuel*

*Based on actual comparative figures on production turns. Fuel savings in individual situations will vary depending upon operating conditions.)

SOURCE: HENDRYX ENGINEERS, INC.

FIGURE 2-2.9 MODERN SHUTTLE KILN USING RECIRCULATION

Surface Areas: Walls - 1105 Ft²
Crown: 960 Ft²

Losses* (MM BTU)

Configuration ⁽¹⁾	Walls	Crown
A	36.4	
B	30.1	
C (2300 2000)	27.0 20.9	
D { 2300 }	24.0	
E		
F (2600) (2000)	18.9 12.4	
G		72.6
H		60.5
I (2000)		26.9
J (2600) (2000)		22.2 10.8
K 2500 2000		20.2 9.4

* Assume average temperature of walls and crown at 1000°F for facebrick firing cycle (Figure 2.2-1) at 140 hours/cycle.

(1) From curves, Figure 2.2-4

TABLE 2.2-4. WALL AND CROWN HEAT LOSS IN A TYPICAL PERIODIC (BEEHIVE) KILN

other simple covering. Heat exchange from these surfaces follows the curves shown in Figure 2.2-10. Consequently, from the Crown G curve, a heat loss of 850 BTU/Ft²/Hr. at, say, 1400°F purged at a gas velocity of about 5 ft/sec can absorb the heat and deposit it in a 1000°F TES ($\Delta T = 400^\circ\text{F}$) device.

2.2.1.3.4 Heat in Dry Flue Gases

Most kiln types are designed to distribute the firing heats evenly across the internal volume containing the ware. Forcing the heat to the lowest sections of the stacked ware is a major problem. Generally, convective paths are created using floor openings (flues) connected to a channel leading to a tall stack. The natural draft provides the flow field needed to distribute the hot gases in a one-pass system. Temperature regulation is achieved by regulating air/fuel feeds to the burners and/or regulating the draft from the stack. With the one-pass system, hot gases flow through the ware, through the floor openings and are rejected to the stack at the leaving temperature.

To date recovery of this heat has not been attempted on a large scale because of the moisture and impurities contained in the gases. Alternative gas flow systems if installed at all, choose between gas heating channels and cooling gas heat recovery. Current designs do not allow for selective gating of flue gases to an energy recovery system after moisture removal is completed, even though at that point the gas is relatively clean. The temperatures at which this final moisture is diffused from the mix is a function of the predominant clay type (See Figure 2.2-7). Above this level, reactions are essentially confined to the ware infrastructure. The primary reason for these losses is in the offsetting of kiln thermal losses associated with maintaining and raising ware (and kiln) temperatures for the firing curve requirements in a reducing environment (minimum excess air-rich fuel mixture).

2.2.1.3.5 Heat of Combustion-Ash and Flue Gases

A small portion of the total energy required is classified as "non-recoverable" losses. Some means of recovery can be postulated for the sensible heat of ash residue and also for any fuel value contained in flue gases due to imperfect combustion. However, considering the potential for other more substantial recoverable amounts of heat available for TES these sources are insignificant and are neglected.

2.2.1.3.6 Heat Loss in Cooling

By far, the cooling gases are the most viable source of gas-contained heat suitable for recovery. In most of the plants contacted by the survey which had considered total systems design, these cooling gases were being used to either dry greenware or pre-heat kilns containing dried ware. Limitations in current practices are:

- 1) Process readiness to use cooling gases, when available.

FIGURE 2.2-10.

HEAT EXCHANGE BETWEEN
GASES AND SOLIDS

- 2) Hot gas handling equipment.
- 3) Plant layouts-proximity of kilns to dryers.

After completion of the final holding period at the specified maturing (or cure) temperature, the ware is cooled at a rate limited by product thermal stress capability. Cooling can also produce strains in kiln wall and crown structures if too rapid. Ware changes during the cooling period occur principally at temperatures over 1000°F where previous crystalline breakdown and glass formation of the silica content during firing is reversed and the vitrification of the mix begins. Recrystallization (annealing) during cooling results in the desired strength and bonding characteristics. Cooling continues until the kiln can be opened, or the ware exposed to ambient plant temperatures, whichever is lower.

After the burners are shut down, total heat available for recovery is the sum of the stored sensible heat in the ware plus that stored in the kiln. For the kiln configuration of Table 2.2-4, with a 70,000 brick capacity (9" standard), with maturing temperature at 1900°F and exit temperature at 300°F, heat stored is shown in Table 2.2-5 for the two wall/crown configurations in Paragraph 2.2.1.3.3. The brick sensible heat portion of the total heat stored is 69% and 90% respectively when comparing non-insulated (case 1) and insulated (case 2) kilns. Recovery of kiln stored heat must consider additional hardware to contain the kiln (or be installed to the structure) and any constraint to limit strain propagation (due to thermal gradients across the thickness of the structure). All kilns have provisions for cooling the interior containing the cured ware. Thus a common mechanism exists to attach an interface for a TES device to the thermal transport loop.

	WALLS(1)	CROWN(1)	BRICK	TOTAL	OIL EQUIV. BBLs.
1. Wall A Crown G	66.3	22.6	189.3	278.1	2087
2. Wall F (2000) Crown K (2000)	12.4	5.8	189.3	207.5	1556

(1) From Figure 8 (1900-300°F)

TABLE 2.2-5 HEAT STORED WITHIN KILN (mm BTU)

2.2.1.3.7 Summary of Heat Losses

The heat demands evaluated in this section are found in all processes associated with ceramics and refractory manufacture. The detailed apportionment of the losses can vary between products depending on initial moisture content, physical configuration, mass and section thicknesses and composition materials (or cure temperature). A tabulation of these losses for a periodic kiln producing 70,000 facebrick is presented in Table 2.2-6.

HEAT LOSSES	HEAT (mm BTU)	% OF TOTAL
1. Moisture and Vapor Removal	39.3	5.1
2. Heat Storage in Kiln Structure	53.6	7.0
3. Heat Loss through Kiln	65.4	8.5
4. Heat Ware (average)	189.3	24.5
5. Flue Gas Losses	378.6	49.1
6. Heat of Combustion	43.6	6.0
Total	769.8	100%

TABLE 2.2-6 PERIODIC KILN LOSSES FOR FACEBRICK MANUFACTURE

Specific percentages do not agree with previous averaged loss estimates due to particular cure temperatures, quantity of ware being fired and kiln construction assumptions. Clearly, however, the contained heat of the ware and flue gases are the immediate items of interest in formulating TES conceptual designs for energy conservation. If conservatively, half of these losses could be recovered, overall kiln efficiency as calculated for this example would increase from 25% to 49% using the formula:

$$\text{Kiln Efficiency} = \frac{\text{Heat of ware} + \text{Recoverable Heat Losses}}{\text{Total heat losses (or heat input)}} \times 100$$

2.2.2 TES INTEGRATION POTENTIALS

Cooling gas, the most commonly recovered waste heat source from kilns, finds uses in ware drying and/or kiln preheating. Both are low energy level functions in terms of temperature requirements. In terms of energy compatibility, these uses conflict with the cooling curves in that cooling commences at the highest temperature of the ware (and kiln) and proceeds towards ambient plant temperature in accordance with the purge gas velocity (time within kiln). Conversely, drying is a time-increasing temperature (to about 190°F) controlled process (a bandwidth of 120°F). Kiln preheating similarly requires gradual heat application but at a more rapid temperature rise-rate since the contents are pre-dried. Rates in this case are limited to conditioning the kiln lining and ware if hygroscopic water is present, or limiting thermal stresses in the expanding refractories. In both instances the dropping temperature of the cooling ware is linked to a demand for increasing temperatures necessitating high dilution ratios at the start while tailoring the gas flow, humidity (or wet bulb temperature) and dry bulb temperature for drying.

Based on the process analysis, three near term uses for TES application can be identified. Flue gases, relatively free of moisture, and cooling gases provide the heat source for charging the TES. Applications for this stored heat include drying, kiln preheating, and augmenting thermal demands along the firing curve. Process integration must consider the TES as a non-critical function in that a worst case analysis can assume the TES depleted due to a return-to-service condition following maintenance or insufficient charge for normal demands. Therefore, all flows, monitors and controls to/from the process should allow for TES by-pass.

Figures 2.2-11 and 2.2-12 show the most promising TES applications. A preliminary heat balance indicates the magnitude of heat capacity associated with each. A comparison with available, recoverable heat, as detailed in Paragraph 2.2.1.3 was used to establish the feasibility of using the TES to satisfy two or more process heat requirements.

2.2.2.1 Drying

Drying time varies with the product mass, shape, and moisture content. For example, a tableware dryer can reduce ware moisture from 25% to 5% in about 15 minutes while a brick tunnel dryer can require up to 30 hours. The ware is raised to a constant temperature by saturated inlet air at about 120°F. The wet bulb temperature is then depressed to permit moisture take-up and removal while the dry bulb is increased to about 180-190°F depending on ware characteristics to shed shrinkage water.

Heat requirements include:

1. Ware heat up to dryer temperature.
2. Moisture removal (to about 9% moisture content).

Figure 2.2-11 shows the arrangement of basic thermal interfaces.

CONTROL VALVE PORTS	FUNCTION
1-2	KILN GAS TO STACK
1-4	KILN GAS TO TES
2-3	TES-KILN GAS TO STACK

FIGURE 2.2-11 TES FOR WARE DRYING

FIGURE 2.2-12 , TES FOR COMBUSTION AIR PRE-HEAT

Assumptions:

1. Dryer linked to 50,000 brick capacity shuttle kiln.
2. Shuttle kiln cycle = 71 hours.

To evaluate the heat flow requirements assume the following case:

Product - Fireclay brick (specific heat = .26)

Dry Weight - 7.5 lbs.

Moisture Content - into dryer 23%

into kiln 10%

Dryer Temperature- 170°F

Time to dry - 25 hours

Dryer capacity - 700 bricks/hr = 6458 lbs/hr greenware

Required - remove 682.5 lbs H₂O /hr.

1. Heat added to raise brick temperature to 170°F =

$$.26 (170^\circ - 60^\circ\text{F}) (7.5) (700) = 150, 150 \text{ BTU/hr.}$$

2. To remove 682.5 lbs/hr H₂O @ 170°

$$682.5 (970 + 110) = 737,100 \text{ BTU/hr.}$$

Product heat required = 887,250 BTU/hr.

3. Dryer losses (Efficiency = 50%) includes:

Heat loss to structure

Heat of waste gas to stack

$$\left. \begin{array}{l} \text{Heat loss to structure} \\ \text{Heat of waste gas to stack} \end{array} \right\} = 887,250 \text{ BTU/HR.}$$

4. Total heat flow = 1,774,500 BTU/hr.

$$= 274 \text{ BTU/hr/lb ware.}$$

2.2.2.2 Combustion Gas Preheat

Kilns and dryers are normally fossil-fired using natural gas, oil, or coal. To effect a changing temperature, dwell (maintain temperature), then adjust to a new temperature, a variable air (and fuel) consumption rate is utilized. In a periodic kiln, this is executed in older installations by one set of burners using manual controls and modulating automatic controls in modern shuttle kilns. Tunnel kilns are divided into zones (or car positions) where constant heat output correlated to the firing curve through the heat transitions along the kiln longitudinal axis accomplishes similar ultimate effects on the ware.

Variations in air/fuel ratios to compensate for changing temperatures results in challenging control problems due to gas temperature-pressure-velocity balances on both sides of the burner. Practical schemes for preheating combustion air in this process include recuperation of waste heat and use of auxiliary heaters. The recuperative method is, in fact, a worse energy conservation approach than no recuperation because the changing temperature of the waste heat stream complicates the already unstable air/fuel control loop and results in greater fuel use due to undumped overcorrecting swings. Auxiliary heating is successfully employed by several kiln manufacturers. This approach results in simpler air/fuel ratio adjustments.

The use of a TES system employing a latent heat storage media provides a new capability to burner-equipped systems, a constant temperature output from recovered waste heat at any temperature at or above the media melting point. A suggested arrangement of equipment is shown in Figure 2.2-12. The projected fuel savings is charted in Figure 2.2-13 as a function of combustion air preheat temperature.

Preheating incoming air to 1000°F saves:

$$\frac{\Delta h_{1000-\text{ambient}}}{\text{heating value}} = \frac{(359-124) \text{ BTU/lb}}{1030 \text{ BTU/ft}^3} = \frac{.23 \text{ ft}^3 \text{ gas}}{\text{lb. air}}$$

to support burner operation. During the low temperature ($T_{\text{kiln}} \ll T_{\text{combustion}}$) portion of the firing curve, excess air requirements will increase proportionate to the temperature difference. At higher temperatures, less fuel is required to raise the combustion gas temperature to the flame temperature, consequently, the value of air preheating with the stored heat increases with increased kiln temperatures.

Kiln burn time for bricks is on the order of at least 25-30 hours, and total cycle times (including ware setting, cooling and removal) of 75 hours in a modern periodic and 40-48 hours for a shuttle kiln are common. This indicates a storage requirement of from 1 1/2 to 3 days unless the TES is linked to dryers, other kilns or supplies preheated combustion air.

A modest sized shuttle kiln of about 15,000 bricks uses about 127 mm BTU (from Table 2.2-2, normalized to 15,000 bricks), or 4230 mm BTU/hr average for a 30 hour burn. Gas flows to produce this heat rate are on the order of

FIGURE 2.2-13
COMBUSTION AIR PRE-HEAT

70 CFM. An analysis of air volumes required for complete combustion yields a volume ratio of about 30 (air/fuel) for an average gas temperature of 1000°F as shown in Table 2.2-7.

PRODUCTS OF COMBUSTION	PRODUCT WEIGHT (LB)	MOLE WT.	TEMPERATURE CORRECTION	VOLUME @ 1000°F (FT ³)
CO ₂	.11688	44	(379*/44) (.11688) 2.8**	2.82
H ₂ O	.09332	18	(379/18) (.09332) (2.8)	5.5
N ₂	.5625	28	(379/28) (.5625) (2.8)	21.3
				29.6

* 379/mole weight = vol. of 1 lb. of gas at std. cond.

** Temperature correction factor:

$$2.8 = \frac{1000 + 460}{60 + 460}$$

TABLE 2.2-7 NATURAL GAS PRODUCTS OF COMBUSTION
AT 0% EXCESS AIR

Consequently, 2070 CFM of air at 1000°F would be required to carry the combustion heat load into the kiln.

If preheated air is substituted for air at standard conditions, gas consumption is reduced 23% with proportionate decrease in air flow to support perfect combustion.

2.2.2.3 Direct Heat Supply

Kiln firing takes place following evaporation of pore water and is temperature controlled to rise at a rate not exceeding the thermal absorption requirements for proper curing of the dried product mix. The total heat flow is as shown

in the example of Paragraph 2.2.2.2 except that additional hot gas is required to compensate for the thermal contribution of fossil-fuel combustion. The design would assume that the TES heat exchanger provides the same heat input. With a "flame" temperature of 3700°F, dilution with about 200% excess air is necessary for temperature stabilization at 1000°F. Excess air admission is one control means used in following the firing heat curve; control of stack draft and fuel flow are also employed.

Maintaining heat transfer dynamics in existing kilns requires that hot gas flow rates be sustained within the kiln. Thus, the sum of the total gas flow requirements at 1000°F is:

Natural gas flow = 70 CFM

Combustion air flow = 2070

200% excess air for 1000 F = 2070 (2)

6280 CFM/lb equivalent gas @ 1000°F

This condition is a direct application of stored heat to augment kiln heat input requirements. Fuel consumption/°F rise is greater in the starting stages of the firing, due to the need to preheat ware and kiln, evaporate pore and chemically combined water (temperatures generally below 1100°F), and maintain or raise ware temperatures according to the firing curve. Consequently, a store capability at temperatures below 1100°F can offset high-grade fuel energy demands for lesser energy availability loads.

2.2.3 TES ENERGY SAVING POTENTIALS

The previous section identified potential TES integration approaches. This section defines the maximum energy saving potential associated with these TES design schemes. The major areas in the periodic kiln cycle for energy recovery by TES have been determined to be the heat flows during firing and cooling. The fraction of total heat input during these portions of the cycle is strongly dependent upon the overall kiln efficiency. An older kiln, without insulation, will reject a greater amount of heat in the flue gases than a well insulated model. A comparison of this is shown below, in Table 2.2-8, for a representative periodic kiln. The energy distribution shown in the table is typical of that seen for insulated and uninsulated kilns currently operating in the field.

ENERGY DISTRIBUTION				
LOSSES	UNINSULATED ⁽¹⁾		WELL INSULATED ⁽²⁾	
	BTU/LB DEMAND	%	BTU/LB DEMAND	%
1. Moisture Heat Vapor Heat in Gas	224	8	224	15
2. Heat Content of Kiln	392	14	50	3
3. Heat through Kiln (walls and crown)	224	8	-	-
4. Heat in floor & flues	280	10	216	15
5. Heat in flue gases	1008	36	453	31
6. Heat or Combustible gas products	168	6	-	-
7. Heat of Cooling	504	18	504	35
Total	2800 ⁽³⁾	100	1440 ⁽⁴⁾	100

TABLE 2.2-8 PERIODIC KILN DISTRIBUTION OF
TOTAL ENERGY INPUT FOR INSULATED
AND UNINSULATED CONFIGURATIONS

TABLE 2.2-8.

NOTES:

- (1) Norton, Refractories - round downdraft kiln @ 18000 ft³/1000 brick, 50,000 capacity, 2280°F.
- (2) Laurel Brick Co.- Insulated thin wall kiln 4100 MCF/1000 brick 208,000 capacity, 1900°F; demand figures corrected to 2280°F and 7.5 lbs/brick.
- (3) Heat values for fireclay brick (cure temperature 2280°F).

$$\text{Total demand} = \frac{\text{Average of fuel consumption}}{\text{Average capacity of kilns}} \quad \text{from Norton (Ref. 1).}$$
- (4)
$$\text{Total demand} = \frac{\text{Heat of cooling (or heat content of cured ware)}}{\text{Kiln efficiency}}$$

ASSUMPTIONS

1. Kiln efficiency doubles as shown in Table 2.2-1 between insulated and uninsulated 32 ft kilns (Nos. 1 and 2 in the table).
2. Ware = 9" standard fireclay brick @ 7.5 lbs.
3. Nominal loss factors for uninsulated kiln as in Table 2.2-3 applied to uninsulated kiln baseline demand of 2800 BTU/lb ware.

A comparison can be made for each of the losses between the older kiln with firebrick construction and new insulated kilns (numbers correlate to Table 2.2-8 entries).

1. Moisture sensible heat and vapor latent heat - remains essentially unchanged as the moisture removal heats are fixed by the ware characteristics. However, the percentage to total heat input is higher because of the redistribution of the other heat apportionments.
2. Insulated kilns were shown (Table 2.2-5) to reduce total heat storage in kiln walls and crown an average of 75-80% by use of insulating firebrick. Ceramic-fiber insulation is likely to improve this even further; however, for this example a 78% reduction is applied.
3. Heat losses are essentially eliminated by newer insulating materials, when coupled to high velocity burners. Results are more rapid ware heating (less wall and crown heat absorption) because of the greater resistance to thermal flows by the insulating media resulting in more of the available energy directed to the ware setting.
4. To achieve the more rapid heating (shorter firing times), gas flows are increased. Due to lagging designs in insulating flues and checkerwork passages, greater heat losses are allocated to these structures, including the kiln floor, as a percentage of the total heat input.
5. The gas heat is projected to lose a lesser percentage of heat due to a higher availability associated with higher flows and turbulence in the course of exiting the kiln. Though more turbulent convectives have increased the heat transfer efficiency in heating the ware, stack (draft) operations vent greater volumes of gas, though at a lesser heat content to maintain good convective patterns, balancing the two dependencies. Thus, while accurate data of flue gas heat flows on newer kilns is unavailable to confirm this, thermal time lag (measured as the time the recorded crown temperature is attained at the base of the stack by the flue gas) would support that a somewhat greater heat transfer between the kiln floors and other swept surfaces lowers the heat content percentage of the stack gases. Thus, the largest losses are associated directly with thermal transport and flow contact areas (items 4 & 5).
6. The introduction of high velocity jet burners with secondary (excess) air additions following the combustion (at almost perfect air/fuel ratios), zone, has essentially minimized combustible products content (unburned hydrocarbons) unless flow rate adjustments are neglected.
7. Heat of cooling (or ware contained heat) following the burn is, of course, unchanged, however, as a measure of kiln efficiency, the percentage of the total heat input is about double that of the old design.

Initially, storage systems would likely be used to recover flue gas exhaust heats and the ware contained heat. Flue gas heat and heat of cooling for typical operating insulated and uninsulated kilns were shown in Table 2.2-8. These two heat sources are the major energy profile components available for TES recovery. Table 2.2-9 shows the maximum possible recoverable heat in terms of percent of total cycle heat input. Thus a TES system with no losses could theoretically recover 54 percent of the energy input to an uninsulated kiln, and 66 percent for an insulated kiln. The flue gas energy breakdown was based on the reference firing curve. This maximum recovery potential was used as the basis for developing annual industry-wide energy savings attributable to TES implementation, discussed in the following sections.

TABLE 2.2-9. TES HEAT RECOVERY POTENTIALS (%)

SOURCE OF HEAT FOR TES RECOVERY	MAXIMUM RECOVERABLE % OF TOTAL INPUT		TES APPLICATION
	UNINSULATED	INSULATED	
300-1000°F	11	10	Dryer
1000°F -Cure temp.	25	21	Dryer and Combustion Air Preheat
Cooling-cure Temperature to 300°F	18	35	Dryers, preheat of Combustion Air or Kiln

Assumption: Firebrick firing in insulated kiln -
cure temperature @ 2280°F

Applying these values to the apportionments of Table 2.2-8 for an insulated kiln flue and cooling gas, the following energy available for recovery (per pound of ware processed) is projected:

TABLE 2.2-10. TES HEAT INPUT AVAILABILITY
(BTU/LB WARE) FOR AN
INSULATED KILN

RECOVERY OBJECTIVE	QUANTITY (BTU/LB WARE)
Flue Gases (300 - 1000°F)	146
Flue Gases (1000 - cure) ⁽¹⁾	307
Cooling gas (cure - 300°F) ⁽²⁾	504

- (1) Cure assumed at 2280°F. For other temperatures add,

$$\frac{(.26) (\text{cure} - 2280^{\circ}\text{F})}{\text{Ratio} \frac{\text{Heat content of ware}}{\text{Heat in flue gas}}} \text{ to}$$

value shown, where .26 is nominal specific heat of firebrick.

- (2) Cure assumed to 2280°F. For other temperatures, adjust this value by
(.26) (cure - 2280°F).

2.3 REGIONAL/NATIONAL ENERGY USE

Over 75% of present energy demand of periodic kiln-using industries engaged in ceramics, refractories and heavy clay products is met using natural gas. These industries are acutely aware of the impending problem they are facing, as natural gas allocations and curtailments will favor supplying the residential and commercial markets. This, with natural gas supplies decreasing and allocation priorities shifting gas away from industry, the affected industries should be scrambling for new or substitute fuels for their survival. Current investigations reveal that only the largest companies are dealing with the issue and even here, one solution is to phase out marginally profitable product lines rather than submit to the energy conservation need. In other cases, inability to afford capital improvements, particularly when linked to an economic slump in construction

and other heavy users of kiln-fired products, has resulted in numerous business failures.

The task of evaluating the worth of a TES system must be justified from considerations of energy demands, the number of periodic kilns in use and energy costs over the forecast period.

The data gathering effort utilized a second-survey questionnaire approach (the first survey was to sample all manufacturing industries; the results of which are reported in Reference 11). Also, contacts were established with the major trade associations. In addition, a literature search of trade publications was conducted. The resulting data allowed an evaluation to be derived relative to:

1. Determining periodic kiln-using companies and plants.
2. Industry energy use (current and projected) based on market demand of products.
3. Energy pricing (current and projected) of coal, oil and natural gas.
4. Kiln capacities and energy consumption (per cycle and annually).
5. Cost savings associated with TES implementation.

The following paragraphs present the methodologies and findings for each of these evaluations. The first major paragraph (2.3.1) presents the analysis of the companies, plant and kiln quantities, as well as an analysis of plant operating capacities relative to energy efficiency. Also included is the derivation of periodic kiln energy consumption and ware capacity.

The second paragraph (2.3.2) provides insights into historical fuel selections and energy projections to 1990 for the major energy consuming SIC 32, kiln-using industries, including assessments of fuel market shares and total energy.

The last paragraph in this section analyzes the plants containing periodic-type kilns in greater detail to establish the differences in potential for conservation impacts as related to use of batch-type kilns.

2.3.1 ANALYSIS OF KILN-USING COMPANIES AND PLANTS

The questionnaire and survey conducted as part of the assessment of energy use (See Appendix A for sample), requested information on plant level characterization of kiln inventories and their specific cycle and annual energy demands.

The questionnaire responses were divided into the three categories and resulting distribution in Table 2.3-1. Representing a response rate of 38%, 67 companies including some which do not operate kilns, returned the forms with contributive information. The response breakdown by kiln type in use is seen in Table 2.3-2.

TABLE 2.3-1. COMPANY RESPONSE DISTRIBUTION

RESPONDING COMPANY CATEGORY	DISTRIBUTIONS OF COMPANIES (QUANTITY) ¹
CONTINUOUS KILNS ONLY	29
PERIODIC/SHUTTLE KILNS ONLY	6
BOTH TYPES OF KILNS	16

¹ Responding companies which reported operating kilns.

TABLE 2.3-2. DISTRIBUTION OF KILNS-COMPANIES

CATEGORY	COMPANIES (%)
CONTINUOUS KILNS ONLY	57
PERIODIC KILNS ONLY	} 12 }
SHUTTLE KILNS ONLY	
CONTINUOUS AND PERIODIC/ SHUTTLE KILNS	
	<u>31</u>
	100

Source: GE Survey and Analysis

2.3.1.1 Estimation of Batch-type Kiln Quantities

The segment of interest is the 43% of the companies having all or some of their kiln inventory as batch-type kilns. To this end compilations of batching kilns (periodics and/or shuttles) were analyzed to develop the needed factors for extrapolating proportions of plants at the national level for overall impact potential for TES. The 43% of the companies having batch type kilns represents 40 plants in 21 companies responding to the survey.

The distribution of both batch type kilns among these plants are as follows (Table 2.3-3):

TABLE 2.3-3. KILN DISTRIBUTION - PLANT LEVEL

PLANT KILNS	DISTRIBUTION (%)	AVERAGE NUMBER OF KILNS	
		PERIODICS	SHUTTLES*
PERIODICS ONLY	50	9	
SHUTTLES ONLY	30		1.6
BOTH TYPES	20	8	1.5

*Shuttle kilns are almost always linked with plants containing periodic and/or continuous kilns while periodic kilns frequently comprise the entire complement of kilns in a plant.

Source: GE Survey and Analysis

Companies having batch-type kilns average 1.9 plants per company. (40 plants/ 21 companies). Thus, if the total number of companies in the kiln using industries is known, the number of plants and the number of kilns can be determined by applying the factors from Tables 2.3-2 and 2.3-3. Figure 2.3-1 shows the procedure for estimating the quantities of each kiln-type if the total number of companies is known. This procedure was followed, and the results are presented in Section 2.3.3. The total kiln inventory from this analysis of survey results agreed quite well with data reported in the literature.

2.3.1.2 Energy Use by Batch-type Kilns

The questionnaire responses included data covering the annual total energy demand by the plant and a breakdown of periodic/shuttle kiln energy consumption per cycle. Ware capacity on both per cycle and annual bases was also included. This data served to develop estimates of energy demand fraction of total plant energy devoted to batch-type kilns for several different categories of plant kiln mix. In addition, knowing the ware tonnage and energy consumption per cycle, a statistical average kiln size was determined.

FIGURE 2.3-1. DETERMINATION OF TOTAL NUMBERS OF BATCH-TYPE KILNS FROM SURVEY RESULTS

For the periodic kiln, these values are 180 tons and 1,130 mm BTU per cycle or about 16 mm BTU/1000 standard brick. Comparing these values to those shown in Table 2.2-2 indicates the "mean" kiln falls into the range of the older, uninsulated types with cycles of about 160-170 hours as might be expected, since the newer thin-walled kilns have not appreciably penetrated the replacement market.

Shuttle kilns are designed for a diverse number of products and capacities depending on a plant's unique requirement as compared to the larger periodic kilns with their generally uniform size range and long firing schedule. The survey data reinforces this point in that capacity and energy consumption values varied widely for a small number of units (254). The validity of the values developed from this relatively small sampling must be suspect. For example, one shuttle kiln's performance indicates an 1107 BTU/lb demand while the mean kiln values are 5100 BTU/lb with 27 ton/cycle and 274 mm BTU cycle as the weighted averages.

Figures 2.3-2 and 2.3-3 present the performance curves of the periodic and shuttle kilns, respectively, as derived using the least squares method applied to scatter diagrams of the survey response kiln data. These curves do not consider configuration specific designs and should only be used as a categorical average of kiln performance for a given tonnage in either kiln. As was shown in Section 2.2.1, specific design features such as the use of ceramic insulation and high velocity burners have a significant impact on energy consumption.

The Refractories Institute has been conducting a voluntary survey of SIC 3255 industries since 1972. Figure 2.3-4 shows the average plant fossil-fired consumption adjusted to eliminate fuels used for mobile equipment, raw materials preparation and unknown "other" functions. The remaining energy is predominantly drying, firing and some plant space heating (about 5% of the total energy). The relevant TRI data, Table 2.3-3 shows "typical" plant energy parameters over a four year period. Reinforcing the overall industry fuel use presented in the first paragraph of Section 2), Figure 2.3-4 shows the gradual shift away from natural gas to petroleum products. The general downturn is a direct reflection of prevailing economic conditions affecting demand for SIC 3255 products. Looking at plant level energy use, Figure 2.3-5, it appears that plant capacities operate most efficiently at about 75% of full production indicated by curves A and B. Curve A shows actual energy demand at reported tonnage produced. By applying adjustments to both the plant capacity % reported (inset to figure) and the energy consumed to estimate a 75% production rate, Curve B results.

In 1975, this industry saw a 9% increase in plants and a concurrent 6% decrease in production capacity indicating possible reductions in production capacity of existing plants and the addition of smaller scale new factories not operating at reasonable capacities by year end. This is shown by the drop in plant average operating capacity (101.8% to 88.9% from 1974 to 1975). When coupled with increasing plant numbers, the trends in Figure 2.3-5 show deviation from the pattern set over the previous three years. Energy intensity trends are in line with the expected pattern, given the problems of gas scarcity and fuel costs to industry during this period, allowing for the inefficiencies associated with new plant start-up and increased change-over from gas to oil.

FIGURE 2.3-2. PERFORMANCE CURVE-PERIODIC KILNS

FIGURE 2.3-3. PERFORMANCE CURVE-SHUTTLE KILNS

FIGURE 2.3-4 FOSSIL ENERGY CONSUMPTION-SIC 3255

FIGURE 2.3-5. PLANT ENERGY DEMAND & PRODUCT ENERGY INTENSITY

TABLE 2.3-3. SIC 3255 DATA

		1972	1973	1974	1975
Energy Demand 10^9 BTU	Gas	9693	10983	11462	8549
	Oil	141	354	702	1846
	Total (1)	9834	11337	12164	10395
(2)	No. Plants	81	88	89	97
(3)	Prod. Cap.	79.5	94.6	101.8	88.9
(4)	Prod. Cap. Tons (10^3)	2156	2173.2	2219.7	2094.6
(5)	BTU/Plant	121.4	128.8	136.7	107.2
(6)	Corrected to 100% Cap.	152.7	136.2	134.2	120.6
(7)	Corrected to 75% Cap.	114.5	102.1	100.7	90.4
(8)	10^6 BTU/Ton	5.73	5.51	5.38	5.58

Calculation:

$$\frac{(1)}{(2)} = (5) \quad \frac{(5)}{(3)} = (6) \quad \frac{75}{(3)} \times (5) = (7) \quad \frac{(1)}{(4)(3)} = (8)$$

Source: • TRI Energy Survey SIC 3255, 1972-1975

• GE Analysis

2.3.2 FUEL MARKET SHARES IN BRICK/CERAMIC INDUSTRY - PRESENT TO 1990

2.3.2.1 Historic Energy Sources

Natural gas is presently the principal energy source for the Brick/Ceramics/Refractories Industries. Table 2.3-4 below shows 1971 energy use in these industries as reported in the Census of Manufacturers. Percent from each source is also presented in Table 2.3-5.

TABLE 2.3-4. ENERGY CONSUMPTION IN SIC 32 KILN-USING INDUSTRIES

SIC	INDUSTRY	ENERGY CONSUMPTION 10 ¹² BTU				
		GAS	OIL	COAL	ELEC.	TOTAL
3251	Brick and Structural clay tile	59.08	3.14	2.88	2.42	67.52
3253	Ceramic Floor and wall tile	4.54	.15	-	.41	5.10
3255	Clay refractories	24.33	1.04	.08	1.03	26.48
3259	Structural clay products, n.e.c.	17.42	1.10	3.02	.63	22.17
3261	Vitreous plumbing fixtures	5.57	.32	.19	.57	6.65
3262	Vitreous china food utensils	2.06	.31	.25	.15	2.77
3263	Fire earthenware food utensils	2.17	.10	.05	.16	2.48
3264	Porcelain electrical supplies	4.12	.29	.20	.79	5.40
3269	Pottery products, n.e.c.	1.96	.01	-	.22	2.19
3297	Nonclay refractories	8.25	1.35	3.25	1.57	14.42
	TOTALS	129.50	7.81	9.92	7.95	155.18

Source: Reference 6.

TABLE 2.3-5. BRICK/CERAMICS ENERGY CONSUMPTION - 1971

SIC	PERCENTAGE OF TOTAL ENERGY USE			
	GAS	OIL	COAL	ELECTRICITY
3251	87.5	4.6	4.3	3.6
3253	89.0	3.0	-	8.0
3255	91.9	3.9	.3	3.9
3259	78.6	5.0	13.6	2.8
3261	83.8	4.8	2.9	8.5
3262	74.4	11.2	9.0	5.4
3263	87.5	4.0	2.0	6.5
3264	76.3	5.4	3.7	14.6
3269	89.7	.2	-	10.1
3297	57.2	9.4	22.5	10.9
ALL	83.5	5.0	6.4	5.1

Source: Reference 6.

The heavy reliance on natural gas is evident from the data. Coal provided the second largest energy source, due to some particular process requirements such as the dead burning of dolomite, but still ranked far behind the over 80 percent natural gas energy share. As a point of reference, about 50% of total manufacturing sector energy was supplied by natural gas in 1971.

The previous industrial surveys, performed during the first phase of the General Electric Thermal Energy Storage Program, provide similar energy source data. Two of the pertinent SIC 32 groups - Brick, SIC 3251, and Structural Clay Products, n.e.c., SIC 3259, were surveyed and yielded results as shown in Table 2.3-6.

TABLE 2.3-6. PERCENT ENERGY BY SOURCE FOR SURVEYED
BRICK/CERAMICS FIRMS 1974

COMPANY	PERCENT OF TOTAL ENERGY USE			
	GAS	OIL	COAL	ELECTRICITY
B1	95.3	-	-	4.7
B2	97.0	-	-	3.0
B3	97.6	-	-	2.4
B4	-	95.8	-	4.2
B5	89.5	6.3	-	4.2
B6	90.4	2.2	-	7.4
B7	76.8	8.2	9.8	5.2
B8	82.9	14.0	-	3.1
B9	94.7	-	-	5.3
B10	89.7	6.7	-	3.6
TOTALS	78.1	10.6	5.6	5.7

SC1	97.6	-	-	2.4
SC2	94.3	-	-	5.7
SC3	54.9	39.0	-	6.1
TOTALS	75.4	19.3	-	5.3

Sources: Reference 7
GE Analysis

Note that natural gas is the primary energy source for 12 of the 13 respondents. The other firm (Brick B4) indicated that no natural gas line was available. Firm SC3 had recently undergone a major expansion for which oil was forced to be the major energy source due to unavailability of gas.

There are clear reasons for the overwhelming preference for natural gas. It is clean burning and can be simply and effectively metered and fired. Interstate price regulation of natural gas has also kept the price low, as shown below:

TABLE 2.3-7. 1974 INDUSTRIAL ENERGY PRICES

ENERGY SOURCE	\$/MILLION BTU
Natural Gas	.65
Oil	1.89
Coal	.46
Electricity	3.58 (\$.012/KW HR)

Source: Reference 8

A further price advantage of natural gas, sometimes overlooked, is the elimination of inventory costs. Pipeline gas is paid for as it is used, not in advance of use. Facilities for storage of fuel prior to use are not necessary. Obviously, many of these and other advantages of gas are diminishing as curtailment becomes prevalent.

The extensive use of natural gas in the Brick/Ceramics industry is a relatively recent development, with coal being the major fuel prior to 1950. The changing fuel mix over the years is typified by that shown in Figure 2.3-6 for Brick (SIC 3251). Note that the percent usage of coal and eventually oil dropped off as natural gas steadily rose through the 1950's. Pollution requirements further spurred natural gas use in the mid to late 1960's.

2.3.2.2 Curtailments

Recent curtailments of natural gas supply have altered the historic trends. The Brick Institute of America, in a 1976 energy survey (Reference 9) found natural gas use among member firms dropping from 83 percent in 1974 to 75 percent in 1975, with oil, propane and coal making up the difference. The Refractories Institute reported similar results with natural gas usage dropping to about 63% in 1974 as compared with over 80% in the 1971 Census of Manufacturers. Oil was the principal substitute energy source.

**FIGURE 2.3-6. BRICK INDUSTRY(SIC 3251)
ENERGY SOURCE:1947-1971**

Curtailments have been particularly severe in the Middle Atlantic and East North Central regions. A survey of Pennsylvania companies, reported in the May 1975 Brick and Clay Record, indicated that 67% of the brick manufacturers and 82% of the refractories manufacturers had experienced natural gas curtailment at some time.

There are several options open to a manufacturer facing curtailment. In roughly increasing order of complexity he can:

1. Cut back production or shut down - a viable option if curtailment corresponds with product demand slowdown, such as might be the case for a northern face brick manufacturer. Also might be the best approach if product has very elastic demand, i.e., cost of alternate fuels cannot be passed on.
2. Purchase propane for standby - expensive energy source but permits use of present firing equipment. Must be classed as interim form of solution.
3. Employ oil standby - requires capital expenses for dual fuel burners, distribution system and storage facilities - Severe energy price increase now but gap is rapidly closing as gas price is deregulated.
4. Install a gas producer - convert coal to producer gas on site. Low cost of fuel offset by high capital investment and increased O&M costs.
5. Use coal as standby - burn finely ground coal, as is extensively done in Europe. Might be best long range problem solution. O&M costs high.

Propane and oil backup are the most widely employed hedges against gas curtailment. Table 2.3-8 indicates locations of firms employing particular actions in face of curtailment as reported in trade publications and the General Electric surveys. A large number of other companies have been forced to reduce production to a level based on gas availability.

TABLE 2.3-8 CURTAILMENT REACTIONS

SOLUTION	STATES REPORTED
Shut down	Illinois, Kentucky, Ohio, Pennsylvania
Purchase propane	Nebraska, Utah, Tennessee, Georgia, South Carolina, Ohio, Colorado
Employ oil for standby	South Carolina, Virginia, North Carolina, District of Columbia, Ohio
Install gas producer	Pennsylvania
Use coal as standby	Tennessee, Texas, Colorado

2.3.2.3 Fuel Switching Options

Significant, in the General Electric survey results, is the fact that a large number of Brick/Ceramics manufacturers are using an alternate energy source for a considerable portion (5-30%) of their process energy requirements. Most of these actions have been the direct result of curtailment or threatened curtailment as mentioned above. Some manufacturers are developing alternate sources as a hedge against price increases on their major fuel. An example here would be a Texas firm experimenting with coal firing of kilns.

The industry can use a wide range of fuels. In Europe the majority of kilns are oil fired, with coal dust firing also quite prevalent. Some kilns are even fired with sawdust. Trade publications in this country have mentioned electric firing as a strong possibility as prices of fossils rise. Electricity is presently used on a very limited level for firing, and only in fused cast operations.

Deregulation of natural gas prices has been promoted by industry sources as the best route to a reliable energy supply for the industry. Although the Brick/Ceramics industries are very energy intensive in terms of BTU per dollar of sales the ultimate product to the consumer is highly labor intensive, thus damping out energy price contributions to final product cost. A case in point is face brick. The March 1976, Brick and Clay Record quoted a national average price for brick in the wall at \$205 per thousand. Using a 1975 average figure of 8460 BTU per brick and taking a high extreme of \$2 per million BTU, only \$17 of the \$205 resulted from energy costs. A recent estimate of mason productivity is 725 bricks per day; 1000 bricks would thus require about 11 hours of skilled mason labor at 12 to 15 dollars per hour or \$132 to \$165.

The result of this economics is relative price inelasticity for the overall industry, but cross elasticity among industry members.* Thus, if one firm is forced to raise price due to use of high priced oil, business will be lost to another company. However, if the entire industry were forced to raise prices due to natural gas price deregulation, impact on industry sales would not be severe.

Deregulation of natural gas price would strengthen the industry energy position in two ways:

1. Demands of competing sectors would be reduced.
2. Alternates (i.e., oil) would become economically competitive.

Curtailment might thus not be as prevalent or have the economic impact that it now has.

* Such products as dinnerware and pottery would obviously present different patterns.

2.3.2.4 Energy Consumption Projections

Brick and Clay Record provides annual forecasts for three major sectors of the Brick/Refractories industry, Brick (SIC 3251), Refractories (SIC 3255 and 3297) and Clay pipe (SIC 3259). These groupings represented about 82% of total Brick/Refractories energy consumption in 1971. The present percentage is even higher due to rapid refractories growth in recent years. The June 1975 production forecasts, shown below, may be optimistic in light of recent industry performance, but are the best available.

TABLE 2.3-9. 1975-1990 PRODUCTION FORECASTS

	BRICK 10 ⁹ S.B.E.*	CLAY PIPE 10 ⁶ TONS	REFRATORIES INDEX (1970 = 100)
1975	7.0	1.50	124
1980	11.0	2.26	150
1985	15.0	2.41	166

* Standard Brick Equivalent

Source: Reference 10

Recent production and energy consumption as reported to FEA (Reference 9) were used to obtain energy per unit output. A conservation rate was then assumed that would result in a 10 percent lower specific energy in 1980 than in 1972. The resultant energy consumption projections through 1990 are tabulated in Table 2.3-10.

TABLE 2.3-10. 1975 - 1990 ENERGY PROJECTIONS

	BRICK	CLAY PIPE	REFRACTORIES	TOTAL
1975	61.0	24.3	90.0	175.3
1980	89.7	34.2	92.4	216.3
1985	114.5	34.2	95.7	244.4
1990	126.0	33.9	98.5	258.4

10¹² BTU

Source: GE Analysis

Disaggregation of total energy consumption into quantities from each source is a bit more tenuous. Government pricing policies, gas availability and allocation criteria and new fossil discoveries are just a few of the many factors that will affect the future energy mix. The industry preference will be to expand or at least retain the present percentage of natural gas use. Oil will be the most desirable alternative, particularly when price parity exists between oil and gas. Coal will have to be priced considerably lower to the industry than either gas or oil to offset its drawbacks. Government incentives may be necessary to achieve extensive coal use in the Brick/Ceramics/Refractories industry.

As an arbitrary baseline, it will be assumed that the absolute quantity of natural gas consumption remains constant at the 1975 level. Electricity will grow at historic rates with oil and coal making up the balance based on the latest (1975) split between the two.

Projected industry energy sources, based on these assumptions, is shown in Table 2.3-11. The rapid growth in coal and oil use required to meet the industry production forecasts is evident from the data. Brick, for example, must increase coal and oil use by a factor of three from 1975 to 1980 to meet a 57 percent production growth projected for the period. Equipment conversion could prove a major barrier to industry growth.

TABLE 2.3-11. PROJECTED ENERGY SOURCES
BRICK/CERAMICS/REFRACTORIES

	1975	1980	1985	1990
Natural Gas	46.2	46.2	46.2	46.2
Coal	5.1	16.3	25.4	28.8
Oil	6.7	21.5	33.7	38.1
Electricity	3.0	5.7	9.2	12.9
Total	61.0	89.7	114.5	126.0

10^{12} BTU

BRICK - SIC 3251

	1975	1980	1985	1990
Natural Gas	56.4	56.4	56.4	56.4
Coal	15.4	16.2	17.0	17.1
Oil	13.1	13.8	14.4	14.6
Electricity	5.1	6.0	7.9	10.4
Total	90.0	92.4	95.7	98.5

10^{12} BTU

REFRACTORIES - SIC 3255, 3297

	1975	1980	1985	1990
Natural Gas	16.6	16.6	16.6	16.6
Coal	3.6	8.5	8.2	6.2
Oil	2.9	6.9	6.6	7.6
Electricity	1.2	2.2	2.8	3.5
Total	24.3	34.2	34.2	33.9

10^{12} BTU

Source: GE Analysis
CLAY PIPE - SIC 3259

Clay pipe faces a similar challenge with about 2.4 times the 1975 coal and oil needed to achieve a fifty percent production growth in 1980. Annual coal plus oil growth rates are shown below (Table 2.3-12) for the 1975-1980 and 1975 to 1990 time frames.

TABLE 2.3-12. AVERAGE ANNUAL COAL PLUS OIL GROWTH RATES
BRICK/CERAMICS/REFRACTORIES

	1975-1980	1975-1990
Brick	26.2%	12.2%
Refractories	1.0%	.7%
Clay Pipe	18.8%	5.1%

Note that Brick and Clay Pipe require a very rapid 1975 to 1980 coal/oil implementation which levels off over the longer time frame. Refractories coal/oil conversion is low due to the low production forecasts for the industry.

It is evident from this energy data that the Brick/Ceramics/Refractories industries will face constantly increasing energy problems. Decrease in availability of the desired fuel, coupled with high prices and conversion problems for alternate sources, should combine to make the industry receptive to energy conservation techniques such as Thermal Energy Storage. This is indeed showing to be true based on the many contacts, interviews conducted and survey responses received with inquiries of interest in TES. Table 2.3-13 shows the company attitudes towards the incorporation of TES into their plants.

TABLE 2.3-13. INDUSTRY ATTITUDES TOWARDS TES

If TES were economically attractive and compatible with your process, how would your equipment use and purchase plans change?

	<u>SURVEY RESPONSES</u>
• No change	17
• Increased use of shuttle and/or periodic kilns	5
• Would purchase additional shuttle/periodic kilns	0
• Would deter purchase of continuous kilns	2
• Would change product mix to utilize benefits of periodic/shuttle kilns	1

If economically priced TES systems became available, when would your operations consider their use?

	<u>SURVEY RESPONSES</u>
• Immediately	8
• Within 2 years	8
• 2-5 years	5
• 5-10 years	0
• Not interested in TES	1
• New equipment preferred over modifications	2

COMPANIES RESPONDING - 24

2.3.3 PERIODIC KILN ENERGY CONSUMPTION

The first step in estimating the potential energy savings attainable from TES in the Brick/Refractories industries is to estimate the energy consumption in periodic kilns. An industry survey was conducted with the prime purpose—the determination of present and future periodic kiln use patterns in these industries. Survey response rate was almost 40 percent, with 67 questionnaire returns from 168 mailings.

Survey results were combined with trade publication data to estimate existing periodic kiln inventories. Appendix A presents the detailed inventory data and energy demands. Shown below are summary data from the survey and literature search on periodic kilns.

	BRICK	REFRAC- TORIES	CLAY PIPE	TOTAL
Plants from Survey	27	23	5	55
Plants from Literature	33	8	5	46
Total Plants Covered	60	31	10	101
Number with Periodics	22	24	9	56
Percent	36.7	77.4	90.0	55.4
Total Shuttle Kilns	9	18	8	35
Total Other Periodics	116	195	56	367

Extrapolation to the entire industry requires an estimate of number of plants in each product class. Recent Brick Industry of America data indicates approximately 400 brick plants in the United States. This is close to the number reported in the 1972 Census of Manufacturers, which also reported totals of 246 plants for refractories (SIC 3255 + SIC 3297) and 119 plants for SIC 3259 which encompasses clay pipe.

Assuming that periodic kilns appear in the entire industry as they do in the sampling, the total industry periodic kiln inventory can be derived. (Table 2.3-14).

TABLE 2.3-14. ESTIMATED PERIODIC KILN INVENTORY
BRICK/CERAMICS INDUSTRIES

INDUSTRY	SHUTTLES	OTHER PERIODICS	TOTAL
Brick	60	773	833
Refractories	143	1547	1690
Clay Pipe	95	666	761
Totals	298	2986	3284

Survey data was statistically analyzed to derive annual kiln energy use. The resultant data is presented below.

TABLE 2.3-15. AVERAGE ANNUAL ENERGY CONSUMPTION
PER PERIODIC KILN

INDUSTRY	SHUTTLES	OTHER PERIODICS	
Brick	11.2	21.5	
Refractories	12.7	15.8	10 ⁹ BTU
Clay Pipe	30.5	17.0	

Source: GE Survey

The data necessarily span a wide range of kiln sizes, efficiencies and utilization rates, and thus represent average rather than typical kiln characteristics. Combining with the previous kiln inventory data yields total annual energy from periodic kilns.

INDUSTRY	ANNUAL ENERGY CONSUMPTION $\times 10^{12}$ BTU			% OF ALL ENERGY
	SHUTTLES	OTHER PERIODICS	TOTALS	
Brick	.7	16.6	17.3	28
Refractories	1.8	24.4	26.2	29
Clay Pipe	2.9	11.3	14.2	58
Totals	5.4	52.3	57.7	33

10^{12} BTU

*Based on data for 1975 in Table 2.3-11.

TABLE 2.3-16 ESTIMATED ANNUAL ENERGY CONSUMPTION IN PERIODIC KILN

The energy consumption values shown represent the most reasonable estimate within the limitations of the survey size. There was some indication of an upward bias in kiln quantities, perhaps due to the stronger interest of a periodic kiln user in the GE study. On the other hand, poor economic conditions may have resulted in much lower kiln utilization than might normally be realized. The SIC 3259 - Clay Pipe data was based on a rather small sample of a diverse grouping and thus is the most tenuous.

2.3.4 TES ECONOMIC IMPACT

Completing the energy assessment of the industry, the potential for marketing an economically viable TES was evaluated on the basis of energy savings credits. Section 3.2 presents the corresponding equipment cost estimates from which the values shown herein can be comparatively judged.

As mentioned earlier, electricity use in kiln firing is negligible, thus, the TES impact is based on the fossil-fuel demand allocated to periodic kiln operations. Table 2.3-17 shows the fossil energy projections originally presented in Table 2.3-11, but with the electrical projections subtracted from the values given.

YEAR	1975	1980	1985	1990
Gas	72	59	53	51
Oil	13	21	24	27
Coal	15	20	23	22
Total Energy - 10^{12} BTU	166	202.4	224.5	231.6

TABLE 2.3-17. FOSSIL ENERGY FORECAST (%)

To evaluate the effect that energy conservation can have on this industry requires forecasting a set of fossil fuel prices and determining the relative escalations these have on the average price of the industry products. The methodology and actual forecasts are shown below in Figure 2.3-7. With energy pricing statistics generally unavailable for the current situation

FIGURE 2.3-7.

INDUSTRIAL FOSSIL FUEL PRICES (\$/MMBtu)

METHODOLOGY

VALUES

	1974 UTILITY PRICES	1974 INDUSTRIAL PRICES
GAS	.55	.72
RESIDUAL OIL	2.021	2.26
COAL	.889	1.00

PRICE FORECAST			
1975	1980	1985	1990
.81	1.46	2.63	4.02
2.39	3.19	4.29	5.27
1.07	1.53	2.17	2.67

it was necessary to find some means of determining current and future industrial fossil-fuel prices. To the extent possible, the approach taken is consistent with published information. The annual escalation rate was applied to the 1974 baseline prices to arrive at the prices shown in the figure. The resulting total fossil energy costs to the industry is shown in Table 2.3-18. It is now

TABLE 2.3-18. TOTAL ENERGY COSTS (MILLION 1974 DOLLARS)

	1975	1980	1985	1990
Gas	96.8	174.3	312.9	474.8
Oil	51.6	135.6	231.1	329.5
Coal	26.6	68.1	112.0	136.0
Totals	175	378	656	940.3

possible to analyze the effects of the fuel demand and price forecasts. This comparison is developed in Table 2.3-19, and clearly indicates the profound near-term effect that gas deregulation will have on costs.

TABLE 2.3-19. ENERGY COST IMPACTS ON INDUSTRY PRODUCTS COSTS

	% Increase		
	1975-1980	1980-1985	1985-1990
Energy Demand	4	2	0.6
Costs	16.7	11.7	7.4
Price of Product Escalation (%)	12.2%	9.5%	6.8%

With energy demand steadily decreasing over the projection period, and taking into account the interfuel switching predicted over this period, the product real costs will have to increase at the rates shown to break even. This neglects any markup and other contributors to cost escalation (inflation, labor costs, etc.). This would seem to substantiate a "don't wait" strategy for accepting an energy conservation approach able to provide benefits in the near term.

Finally, relating these data to a TES product, the total energy consumption estimate developed in Table 2.3-16 is used for the approximation sought for an average dollar savings. It should be clarified here that the prices projected are nationally averaged and are not indicative of regional and local utility

rates. For example, Figure 2.3-7 shows natural gas at \$0.81 per million BTU (1975) while it is known that over \$2.00 per million BTU is currently the norm in Pennsylvania and Ohio. Consequently, with the share of natural gas at 75% of the market, the TES costs are low by close to a factor of two in some areas of the country.

The data in Table 2.2-9 suggests that for an uninsulated kiln, which comprises the vast majority of presently active periodic kilns, a maximum heat recovery potential of 54% can be realized. Allowing for an overall TES efficiency of 50%, this savings is estimated at 27% of the total energy dedicated to periodic kilns. Reconciling this impact with the fuel costs and energy allocated to periodic kilns, the cost savings are presented in Table 2.3-20.

TABLE 2.3-20. ANNUAL SAVINGS WITH TES (1974 MILLION \$)

ANNUAL SAVINGS WITH TES (MILLION \$)				
	1975	1980	1985	1990
Industry	15.6	33.7	58.4	83.8
Plant	.040	.086	.149	.213

- Assumptions: 1. % energy to periodic kilns is a constant - 33% (from Table 2.3-16).
2. Number of plants are constant.

Converting these annual savings into two methods of capital financing, a fixed levelized annual cost and the more common life cycle cost estimates, the cost targets for a new TES design are determined. Table 2.3-21. As will be seen after reviewing the estimated costs of the concepts included in Section 3.2, several offer immediate benefits, well within these amounts.

TABLE 2.3-21. TARGET COSTS FOR TES

YEAR	BASE YEAR SAVINGS \$	VALUE FOR ANNUALIZED FIXED CHARGE RATE OF 22%	MULTIPLIER FOR FUEL PRICE ESCALATION=5% AND 30 YEAR EQUIPMENT LIFE*	LIFE CYCLE VALUE OF TES SYSTEM
1975	40,000	182,000	1.596	290,000
1980	86,000	391,000	↓	624,000
1985	149,000	677,000	↓	1,080,000
1990	213,000	968,000	↓	1,545,000

* USE 1.423 FOR 20 YEAR LIFE

2.4 VENDOR STUDY

To assess the potential for introducing TES into the brick/ceramic industry as an energy conservation measure, vendors of refractory manufacturing were contacted. Surprisingly, several of the larger equipment manufacturers were not cognizant of thermal energy storage use. This is particularly interesting because of their unanimous recommendation to recycle cooling gases for drying and kiln-preheat functions. The fired ware is in itself a TES in this mode, along with the kiln structure.

The following sections briefly summarize the current assessment of TES market potential.

2.4.1 OUTLOOK

The promising markets for periodic (shuttle) kilns lie in the refractories, insulating ceramics, and abrasives manufacture. Typically, these industries offer many different product shapes and sizes. To maintain production versatility, shuttle kilns are usually chosen as they have easily programmed timing/temperature cycles. These programs are frequently controlled by cams selected to produce required burn parameters. Some high volume porcelain products are processed through a continuous kiln; however, periodics are vital to meet the flexibility demanded by the smaller manufacturer of diversified products. Thus far, little attention by the kiln manufacturers has been devoted to new designs of beehive kilns. Because these are usually designed by the plant engineering staff with the "help" of component suppliers' sales engineers, OEM interest is minimal. Construction is also oftentimes by a plant construction team; therefore, with little potential for profit, equipment fabricators are not encouraging any resurgence of round, downdraft kilns, despite recent important energy savings improvements. Equipment manufacturers are "pushing" for the replacement of older periodic kilns with tunnel kilns on the basis of increased energy efficiency especially in the facebrick industry where variations in product configurations have narrowed to only a few basic structural configurations with the emphasis on cosmetic variety (color, texture) easily implemented by mass production, continuous machines.

2.4.2 CHALLENGES

Periodic kiln configurations are specified by the following variables:

1. Wall height (surface area).
2. Crown diameter (crown area and arch).
3. Burner numbers (heat input flow/zone).
4. Burner orientation (plume vectors).
5. Burner height (heat gradient and convection).
6. Flue patterns in kiln floor (draft induced heat distribution).

In most cases, each of these major design options varies independently of the other features, although some optimizations have been recently introduced as a result of technology advances in insulating materials and burner designs. Prior to these advances, no special combinations were considered "standard" and each plant's kiln designer employed his individual preferences to meet the unique product, or production capacity, parameters. Trends towards uniformity or standardization of equipment are slowly penetrating kiln design approaches; however, the traditional method of plants designing and constructing their own periodics is still very much the norm. Each of the stated variables ultimately relate to heat convection rates and flow patterns.

With the improved thermal performance now being reported by users of thin-walled, fiber-insulated kilns with high velocity burners, increased attention to even heat gradients, coupled to rapid temperature rise times (as limited by ware characteristics) are a major consideration to designers in minimizing ware firing rejections. High combustion efficiencies have been achieved with the successful introduction of high velocity burners. Additional improvements in fuel consumption are possible using preheated combustion air to reduce the oxidation reaction time within the burners due to air heating to the flame temperature.

The other challenges are linked to kiln loading and unloading. With 60 hour cold-to-cold cycles possible in modern beehives, 16 hour load/unload times need to be improved. Another area of further research is in coupling coal (dust) to the high velocity burner, as a primary fuel in light of the increased competitiveness of gas and oil and the abundance of coal. This is an especially worthy objective as coal reserves are in proximity to this industry's major concentration of producers.

2.4.3 EQUIPMENT COSTS

Periodic kilns do not represent a major capital expense to the plant compared to tunnel kilns. Several sources have indicated that for larger capacities, a tunnel kiln costs about twice that of the equivalent capacity of shuttle kilns, but that as capacity decreases, these costs converge. In a replacement plan, tunnel kilns can take a year to construct and start up. If older beehives are leveled to make space for the tunnel kiln, plant output is not realized for that year resulting in lost revenues and capital outlays, a poor combination in an industry with a widely fluctuating market demand.

An article by Acme Brick Co. describes an acquisition of four modern round beehive kilns with a 120,000 brick (9" std.) capacity at a cost of \$95,000 (Brick and Clay Record, November 1974). A shuttle kiln designed for refractories products with an energy conserving heat flow concept and a modern IFB liner costs about \$100,000. Capacity is estimated at 15 tons of set ware on kiln cars or 21,000 (9" standard) brick equivalents assuming a 33% void space in the setting.

Operating costs include fuel and electrical power for combustion, fans and blower operations and kiln maintenance. Of interest here is the cost of thermal energy. From the table of fuel consumption by downdraft periodic kilns (Table 2.2-2) reported by Norton, about 150 gallons of oil equivalent per

1000 bricks is an average demand of the older kilns. Assuming a current price of \$13.00/BBL of oil, fuel costs/1000 bricks are approximately \$43. Thus, for a 50,000 brick periodic kiln cycle, the thermal energy costs are in the order of \$2150. If the kiln is operated at 130 hour cycles, 5 days/week, the yearly fuel energy cost amounts to \$103,200 (48 cycles annually) or about equal the capital costs of a new modern kiln capable of lowering fuel demands to about 45 gallons of oil per 1000 bricks, a 70% reduction. With this savings in fuel costs, a new periodic will show a payback period of less than 1 1/2 years! Several company executives stated that their capital and improvement programs must be justified using a 3-4 year payback period due to the uncertainty of their future market situations.

2.4.4 THE VENDOR POINT OF VIEW ON TES

The several interviews and contacts with industry agencies other than the end users (trade associations, consultants and equipment manufacturers) produced varied opinions. Most of the individuals did not clearly understand the TES function initially to develop a position. After orienting their thinking to the idea of time-linked thermal energy recovery and re-use, their interest heightened. In the case of Hendryx Engineers, Mr. Gordon Fay, inventor of the new heat recirculating shuttle kiln (described briefly in paragraph 2.2.1.3.2) could envision several possible applications, given a proven TES system, including an integrated design with his new kiln. Having published several papers on kiln energy conservation(3,4) Fay, viz-a-viz Hendryx Engineers, are a good sounding board on the reasonableness of TES practicality, providing the device, in fact, fulfills the requirements of the applications identified.

Shuttle kiln sales are highly dependent on industrial growth and the present outlook (See paragraph 2.3.2.4) indicates a slow but steady increase in product demands. Initial efforts for introduction of TES devices must therefore address plant retrofit schemes, where the greatest impact in energy savings can be realized in the near term. This assumes a highly successful market penetration rate. Referring to the plant manager interviews, their immediate requirement for capital investment is a realizable payback of about 3 years for an economic justification; however, given a curtailment scenario impacting their productivity (which would also be suffered by local competition), these cost values are: secondary.

2.4.5 INITIAL TES MARKET OPPORTUNITIES AND LOCATIONS

In conjunction with the analysis of the ceramic/refractory industry usage of periodic kilns (Paragraph 2.3.3) as determined by the industry survey responses, several primary TES opportunities have been identified. In defining these prospects, a maximum impact was estimated based on an ideal set of sales achievements by TES system suppliers. Knowing the regional industry concentrations and present fuel demands, weighted averaging was used to distribute the estimated total energy savings. This was presented in Paragraph 2.3.3. Logically, a major market concentration should couple high dependency on natural gas and plants with multiple installations of periodic kilns.

The Brick/Ceramics/Refractories industry originally centered in Ohio due to the ready availability of clay and coal. As low priced natural gas became available the industry spread to the southeast and southwest, gaining a further advantage from the inexpensive labor available in these regions.

Today the industry encompasses almost every state, but still retains heavy geographical concentrations for certain products. Figure 2.4-1 illustrates the differences in concentration that exist within the industry. Brick (SIC 3251) is relatively unconnected with the top four states containing about 35 percent of the total manufacturers, while almost 50 percent of Refractories (3255, 3297) manufacturers exist in the two states of Ohio and Pennsylvania alone. Based on this data it can be concluded that, in general, these industries locate today at their market source. Refractory products are heavily consumed by the iron and steel and glass industries, which are heavily concentrated in the Ohio-Pennsylvania region. Facebrick, on the other hand, sees widespread geographic use, and plant locations reflect the relative lack of consumer concentration.

Clay pipe (SIC 3259) presents a somewhat different pattern, with Ohio at 25.7 percent and California at 11.4 percent of industry firms, far ahead of other states. In aggregate, about 28 percent of Brick/Clay/Ceramics manufacturers are located in Ohio and Pennsylvania.

SOURCE: REFERENCE 6

Note: Firms with 20 or more employees (=97% of production).

FIGURE 2.4-1. BRICK & REFRACTORIES GEOGRAPHIC CONCENTRATION

2.5 SECTION 2 REFERENCES

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SECTION 3

THERMAL ENERGY STORAGE CONCEPT DEFINITION

This section presents the approach, analysis, and evaluation of the TES concepts considered for application to periodic kilns, to realize the kinds of energy conservation reported in Section 2. To this end, a detailed thermal systems analysis was performed, and based on these results, several near and intermediate term TES media, containment, and heat exchange concepts were synthesized and evaluated. In addition, one concept embodying somewhat greater risks was identified for a look at a possible next generation configuration.

3.1 CONCEPTUAL SYSTEM PERFORMANCE

The energy savings potential for kiln waste heat recovery with thermal energy storage (TES) was determined by a detailed energy analysis study. A computer program was required to assess the time dependent interactions between kiln firing, waste heat availability, a thermal storage media, and a heat process requirement or energy demand. The program required a high degree of flexibility for making parametric evaluations of various TES concepts, multiple types of kiln operations, various demands, and to provide preliminary component sizing and definition.

The key features of the computer program are that it:

- Provides dynamic simulation of energy flow throughout system.
- Utilizes actual kiln firing data and demand data as input (Section 3.2.4)
- Models both latent and sensible heat storage
- Maintains energy storage inventory and energy savings.
- Simulates three demand requirements.
- Simulates multi-kiln firing and demands.
- Provides preliminary design component definition.

The simulation model consists of three components: a stack or waste heat energy recovery component, a TES media component, and a demand component. The model maintains an energy inventory throughout the system by calculating an energy balance for each time step which is a program input. The following sections describe the details of the program, the inputs utilized, and the analysis results.

3.1.1 PROGRAM DESCRIPTION

3.1.1.1 Stack Energy Recovery

The forcing function to charge the TES is the available waste heat as a function of the kiln firing data. The details of the kiln firing are characterized by measured data from a typical operating kiln selected as a baseline for the study. These data include the exiting exhaust gas temperature or stack temperature, the kiln roof or crown temperature, the fuel flow rate and either the excess air flow rate or the O₂ content in the stack. The resulting firing curve is shown in Figure 3.1-1 for the reference kiln and presented in more detail in Section 3.2.4.1. The data represents a firing cycle of 52 hours and a 32 hour cool-down period for a 24 hour total cycle. Assuming perfect combustion using natural gas, the sensible waste heat available in the stack can be determined from data presented in Reference 1 and shown in Figure 3.1-2. For example, assuming a 1500°F exiting gas temperature with a 50% excess air flow, the heat content in the products of combustion is the sum of 64 BTU/Ft³ of gas plus 36 BTU/Ft³ X 50% or 18 BTU/Ft³ heat content in the air for a total of 82 BTU/Ft³ available above 60°F. This value multiplied by the fuel flow rate gives the energy available as a function of time.

This data is stored internally within the program as a curve fit. For the reference firing curve, Figure 3.1-3 presents the percent of the total fuel energy input to the kiln which is lost up the stack as a function of the firing time. Over the firing cycle approximately 44% of the energy is lost up the stack. The mass flow rate of the exhaust gases is also shown in Figure 3.1-3.

Two options exist for simulating recovery of this available waste heat. The first option assumes a conventional counter-flow heat exchanger between the exhaust gas and a transport media to the TES. This system is shown schematically in Figure 3.1-4. The transport fluid conditions entering the heat exchanger are dependent on the current state of the TES with a constant volume flow assumed. The heat exchanger coefficient, UAL, (heat transfer coefficient times surface area), is an input parameter which is assumed constant for a given case.

The heat transferred from the stack to the transport medium is then given by:

$$(1) \quad Q_{HX} = \epsilon * C_{MIN} * (T_{KILN \text{ EXHAUST}} - T_2) * \Delta t$$

where:

ϵ is the conventional heat exchanger effectiveness as defined in Reference 2 where $\epsilon = f(UAL, C_{MIN}, C_{MAX})$

$C_{MIN} = \dot{m}C_p$, is the minimum heat capacity rate which is defined as the product of the mass flow rate of the fluid times the specific heat of the fluid.

$C_{MAX} = \dot{m}C_p$, is a maximum heat capacity rate.

$T_{KILN \text{ EXHAUST}}$ is the stack temperature.

T_2 is the entering transport fluid temperature, as shown in Figure 3.1-4.

Δt is the duration of the calculation time step.

FIGURE 3.1-1

REFERENCE KILN FIRING CURVE

FIGURE 3.1-2. SENSIBLE HEAT IN PRODUCTS OF COMBUSTION FOR NATURAL GAS

FIGURE 3.1-3
REFERENCE KILN PERFORMANCE

FIGURE 3.1-4. SYSTEM SCHEMATIC OF EXTERNAL TES/STACK HEAT EXCHANGE

The exiting transport fluid temperature leaving the heat exchanger and entering the TES, T_1 , is then:

$$(2) \quad T_1 = T_2 + Q_{HX} / (mCp)_{\text{TRANSPORT FLUID}}$$

These equations thus define the quantity and temperature of the recoverable waste energy transferred to the storage system. If the TES is at a higher temperature than the stack temperature, the exhaust gases bypass the heat exchanger as shown in Figure 3.1-4.

The second recovery option assumes an integrated heat exchange system within the TES. This heat exchange is also modeled by a UA to allow parametric evaluation of the heat exchanger parameter for different integral heat exchange schemes, see Figure 3.1-5. T_1 in this option is the kiln exhaust temperature and T_2 is the exhaust gas temperature leaving the TES. Assuming an average TES temperature, T_3 , for the time step, the heat transferred to storage is given by:

$$(3) \quad Q_{HX} = \frac{UA_1}{2} \left[T_1 - 2T_3 + \frac{\frac{mCp}{2} T_1 + UA_1 \left(T_3 - \frac{T_1}{2} \right)}{\frac{UA_1}{2} + mCp} \right] \Delta t$$

where mCp is the stack gas heat capacity rate as before. Again, if the TES temperature is above the stack temperature, the flow bypasses the TES.

3.1.1.2 Thermal Storage Media

Both a sensible heat storage and a latent heat storage option were included in the program for parametric evaluations. The model accepts as input the heat capacity of the storage medium in BTU/lb as a function of storage temperature. Additional input includes the total storage mass, containment size and insulation resistance or R factor. The TES temperature, T_3 , is calculated for each time step based on the previous temperature and an energy balance between the energy transferred to storage and the energy removed from storage, either delivered to the demand or lost through the insulation to the environment. The energy deliverable to the demand is transferred from the storage medium to the transport medium through another integral heat exchanger.

The discharge heat exchange is modeled similar to the integral heat exchange on the charge side only with a heat transfer coefficient of UA_2 .

The deliverable energy is thus given as:

FIGURE 3.1-5. SYSTEM SCHEMATIC OF INTEGRAL TES/STACK HEAT EXCHANGE

$$(4) \quad Q_{\text{DELIVERED}} = \frac{UA_2}{2} \left[T_6 - 2T_3 + \frac{(\dot{m}Cp)_D T_6 + UA_2 (T_3 - T_6)}{\frac{UA_2}{2} + (\dot{m}Cp)_D} \right] \Delta t$$

where:

T_3 is the average TES temperature.

$(\dot{m}Cp)_D$ is the heat capacity rate of the transport medium (air) to the demand.

T_6 is the air temperature entering the TES on the discharge loop shown in Figure 3.1-4 or 3.1-5.

T_6 can be the outside air temperature if the discharge loop is an open cycle or the return air temperature from the kiln if the discharge loop is a closed cycle.

A comparison of the stored energy capacity as a function of storage temperature for potential storage media is shown in Figure 3.1-6. The high storage capacity for the latent heat material (NaOH) is noted over the media melting range (latent heat absorption).

3.1.1.3 Energy Demand Options

Section 2.2.2 identified three end uses for stored energy in a brick plant as viable options for energy savings. These include drying of greenware, preheating of combustion air, and preheat of the kiln and ware during initial phases of the firing cycle. Each of these demands was modeled as an energy and temperature requirement to determine energy savings for the option. At each calculation time step a check is made to determine if the energy and temperature in storage is greater than the demand energy and temperature requirements. These requirements are shown in Figure 3.1-7.

The profiles for the temperature requirement are input as a function of burn time and the demand energy requirement is calculated corresponding to the specific demand option.

For the combustion air preheat option a preheat temperature requirement of 600°F was considered. The energy requirement is then calculated by:

$$(5) \quad Q_{\text{REQ'D}} = (\dot{m}Cp)_D (600^\circ - T_6) \Delta t$$

where $(\dot{m}Cp)_D$ is the same mass flow heat capacity rate through the kiln as in the reference kiln firing with no preheat. T_6 is shown on Figure 3.1-5 as the temperature entering the TES on the discharge side and for this application is outside ambient air assumed at 75°F. The fraction fuel savings provided by using preheated combustion air is determined by the ratio of the amount of delivered preheat energy to the sum of the delivered preheat energy and the net energy supplied (Q_{NET}) to the furnace as shown in Reference 7.

$$(6) \quad \% \text{ FUEL SAVING} = \frac{Q_{\text{REQ'D}}}{(Q_{\text{REQ'D}} + Q_{\text{NET}})}$$

Q_{NET} is the difference between

FIGURE 3.1-6. ENERGY STORAGE DENSITY COMPARISON

FIGURE 3.1-7. DEMAND REQUIREMENTS OF STORED ENERGY

the fuel heat value input without preheat minus the energy lost up the stack. The fuel savings is determined at each calculation time step and integrated over the burn cycle.

The second demand is kiln preheat. In this option, the required temperature is defined as the:

$$(7) \quad T_5 = T_{\text{KILN EXHAUST}} + \frac{Q_{\text{NET}}}{(mCp)_D}$$

where Q_{NET} is the same as defined above. This discharge mode is planned as a closed loop so the temperature, T_6 , entering the TES will be the exiting temperature from the kiln (See Figure 3.1-5). Q_{NET} is thus the energy required to provide the heat to bring the ware to the curing temperature and to offset the kiln losses. The stack losses are zero since this is a closed flow loop. The air to preheat the kiln/ware is not necessarily supplied through the burners as indicated on Figure 3.1-5, but can enter at some other inlet to the kiln. This provides for maximum use of the stored energy. Stored energy would be used to meet the firing curve requirements until the TES temperature drops below the required temperature. At that point stored energy could still be drawn and the burners lit to supply only the balance of energy required.

The third demand modeled is ware drying. Presently, the cooldown air can be used directly for drying the ware but drying requirements are often out of phase with cool-down energy availability. A dryer input temperature requirement of 300°F is needed for drying and an energy requirement of 240 BTU/lb of brick ware to be dried was assumed. This value is an average obtained from data supplied by several brick manufacturers. The inlet temperature to the TES on the discharge side, T_6 , in this case is outside air at 75°F. After passing through the drying ovens (separate from kilns) the moisture laden air is exhausted to the atmosphere. Figure 3.1-7 summarizes the temperature and energy requirements profiles over the firing cycles for the three demands.

3.1.1.4 Program Input

The program input includes all the parameters defining the reference kiln firing curve, the storage component details and the demand energy options. Each of the pertinent input parameters are listed below:

- TM - Time in hours into the firing cycle at which kiln data is input.
- TCRM - Crown or kiln roof temperature in °F at each time TM.
- TSTK - Stack or kiln exit temperature in °F at each time TM.
- FUEL - Gas fuel flow rate in CFH at time TM.
- EXO2 - % O₂ content in stack gas at time TM.
- TMD - Time in hours for the demand requirements.

TDEM - Required demand temperature in $^{\circ}\text{F}$ at time TMD.
 DFUEL - Fuel flow in CFH required to supply demand without storage.
 DEXO2 - % O_2 content in stack gas at time TMD for the demand kiln.
 UA1 - Heat transfer coefficient for heat exchange to TES on charge loop.
 (BTU/ $^{\circ}\text{F}$ -Hr.)
 UA2 - Heat transfer coefficient for heat exchange from TES on discharge
 loop. (BTU/ $^{\circ}\text{F}$ -Hr.)
 CPA - Specific heat of discharge transport media (BTU/LB- $^{\circ}\text{F}$)
 FLOWD - TES discharge flow rate CFH
 MASS - TES mass in pounds.
 SENS - Specific heat of sensible heat storage media (BTU/LB- $^{\circ}\text{F}$)
 CLAT - Latent heat of phase change storage media (BTU/lb.)
 TMELT - Melt temperature of phase change storage media ($^{\circ}\text{F}$).
 TO - Initial storage temperature - ($^{\circ}\text{F}$).
 DT - Calculation time step.
 HXFLUD - Mass capacitance flow rate of charging transport medium for
 external heat exchanger option (BTU/ $^{\circ}\text{F}$ -Hr.)
 IHX - Heat exchanger option selector.
 RINSUL - Insulation R value for storage containment insulation.
 ISUPPLY - Demand option selector.
 TI - Initial cycle time.
 NPRINT - Output printout frequency.

3.1.1.5 Program Output

The program output includes integrated values of selected variables over the specified printout time intervals along with total cycle summaries. The list of output parameters includes:

TIME - Time in hours from the beginning of the burn cycle.
 DEMAND - Demand energy in KBTU.

QHX - Energy transferred to storage from the source (KBTU).
 QTES - Energy removed from storage to demand (KBTU).
 LOSSES - Energy lost from the TES unit to the environment KBTU.
 AUX - Conventional energy supply required to meet the demand KBTU.
 T1, T2, T3, T4, T5, T6 - Instantaneous temperatures in °F at locations indicated in Figure 3.1-4 or 3.1-5.
 %STK - % of fuel input energy going up the stack.
 %RECOV - % of energy going up the stack that is recovered.
 QSTORO - Current energy in storage (BTU/lb).
 %SUPP - Fraction of the demand energy supplied from the TES.
 SAVG - Average % fuel saving.
 HXEFF - Charge loop heat exchanger effectiveness.
 DEFF - Discharge loop heat exchanger effectiveness.
 These parameters provide an overall assessment of the energy flow throughout the system.

3.1.2 RESULTS OF PARAMETRIC ANALYSIS

The program provided several parametric performance evaluations of a kiln/TES system. The results do not represent optimized systems but reflect the trends in system sensitivity to key parameters. Initially, a comparison of system performance was made for several different candidate storage media assuming only one reference kiln charging the TES and no demand on the TES. This case represents the minimum amount of stack energy recoverable since the TES continually increases in temperature until the heat transfer from the exhaust gas is negligible. The results of these cases are shown in Figure 3.1-8, and reflect several interesting factors.

First, as is expected, the amount of energy recovered and stored increases with the specific heat, C_p , of the material for any given TES mass. Note that for the phase change material, NaOH, an equivalent C_p is shown which combines the sensible and latent heat, 150 BTU/lb, of the sodium hydroxide. Although more energy is recoverable for the higher specific heat, it is at a lower temperature and therefore may not be usable for a particular demand application, as illustrated by the temperatures shown along the dashed line at the TES mass of 7×10^5 pounds of Figure 3.1-8. This indicates the need for parametric comparisons for the media and types of demand to optimize system performance. In addition, the storage media or containment package may impose further restrictions on the maximum allowable temperature that the system can withstand without corrosive degradation. Maximum operational limits were imposed for the iron and sodium hydroxide systems which limits the energy recovery potential below the T_{MAX} points shown in Figure 3.1-8. In the case of the iron media, the 1000°F limit significantly reduces the amount of energy recoverable.

FRACTION OF STACK ENERGY RECOVERED

FIGURE 3.1-8. TES ENERGY RECOVERY FROM ONE KILN
NO DEMAND, TES CHARGED

A final observation is that all the media attain the same asymptotic limit on recoverable energy but at different temperature levels. As the TES mass increases, the systems become heat exchange, UA, limited which accounts for the asymptotic limit.

Single Kiln Operation

Comparisons were also made of the amounts of recoverable energy for the three different demands again assuming only one reference kiln firing as the TES charging source. Results from these runs are shown in Figures 3.1-9 to 3.1-11. The figures show the performance sensitivities of several key system parameters. Figure 3.1-9 shows the results for the ware drying demand defined in Figure 3.1-7. The system performance measure is the percent of the total drying demand supplied by the TES system. The system parameters included the thermal storage mass, the initial storage temperature and the heat transfer coefficients in the TES charge and discharge loops (UA1 and UA2). A brick storage media was assumed with integral heat exchange similar to the flow through a checkerwork.

A distinct optimum TES size is noted in the first curve. As the storage mass is increased beyond the optimum point the average storage temperature level is lower and the TES satisfies a smaller portion of the demand. The second curve shows the expected increase in system performance due to an increase in initial storage temperature. An initial storage temperature of 550°F will provide all of the ware drying demands. The third curve indicates the size of the heat transfer coefficient on the charge loop to be near optimum. Any further increase results in only small system performance improvements. On the discharge loop, however, the curve is still relatively steep, indicating the further improvement for higher UA values. Each of the curves has a common reference point as indicated on the figure. The same parametric sensitivities for the kiln preheat demand is shown in Figure 3.1-10. These results are plotted versus actual energy saved instead of percent energy savings. Again, an optimum TES size is evident for the application. The first curve also shows the effect of the initial storage temperature on the optimum TES size. As the initial storage temperature is increased, the optimum storage size decreases. Maintaining the same TES mass and increasing the initial temperature shows an increasing system performance, as before. The last two curves show that both the charge and discharge loop UA affects the energy savings significantly and higher values are indicated for optimum performance.

Figure 3.1-11 shows some typical parameter evaluations for combustion air preheat demand. The energy demands are defined in Figure 3.1-8 with the potential energy savings determined with equation (6) in the energy demand section (3.1.1.3). The first curve shown in Figure 3.1-11 is the maximum energy savings attainable by preheating the combustion air to the temperature indicated. For the parametric cases studied a preheat temperature of 600°F was considered so the maximum fuel savings is 21%. The second curve in Figure 3.1-11 shows the optimum TES size with respect to fuel savings.

FIGURE 3.1-9. SYSTEM PARAMETER SENSITIVITY
BRICK DRYING WITH TES ENERGY

FIGURE 3.1-10. KILN PREHEAT PARAMETER SENSITIVITY

FIGURE 3.1-11. PREHEAT OF COMBUSTION AIR
(BRICK TES)

Although the fuel savings indicated are in the 5 to 10% range, these values are between 25 and 50% of the maximum fuel savings possible by preheating the combustion air to 600°F. For these parametric cases, both UA1 and UA2 were assumed to be equal and thus were varied simultaneously. It is noted that increasing UA increases the optimum storage system size. This trend implies that an improved heat transfer capability on the charge and discharge loops results in more effective use of the TES. The fuel savings variation with the UA is shown separately in the last curve on the figure. The curve shows a leveling trend implying an asymptotic UA value with respect to fuel savings.

Multi-Kiln Operation

All of the above results were determined based on only one kiln charging the TES. In practical brick plant operations, several kilns may be operating simultaneously. These kilns are fired according to some schedule allowing for loading and unloading of the brick. There are many possible random firing schedules; one possibility based on operations surveyed is shown in Figure 3.1-12. This weekly schedule shows a four kiln firing schedule. One kiln is fired each day and the "U" and "L" indicate unloading and loading times. The firing cycle is the 52 hour reference cycle. Having simultaneous kiln operation allows either concurrent TES charging from two or more kilns if the TES temperature is below the stack temperature of the gases from each kiln, or continuous TES charging from the highest regime of the firing curve from each kiln. This latter case provides the highest heat transfer capability to the TES due to the higher temperature difference between the exhaust gas and the TES when charging at the peaks of the firing curves.

The random schedule also provides several alternatives for discharging the TES. Energy could be delivered only over portions of each firing curve in an effort to optimize the energy usage.

The schedule in Figure 3.1-12 was used to provide a preliminary estimate of energy savings potential for multiple kiln operations. The TES was considered to be charged during the peak of each firing cycle. The demand assumed was a kiln/ware preheat with the preheat being delivered during the first 24 hours of each firing cycle. The resulting charge and discharge temperature profiles are shown in Figure 3.1-13 along with the TES temperature response. A brick checkerwork storage media was assumed initially at a temperature of 1200°F. The TES temperature is seen to decrease during the initial demand requirements and then increase as the demand temperature approaches and then exceeds the TES temperature. The curves on the top of the figure show the fraction of the demand energy that is supplied from the TES as a function of time. At the beginning of each demand requirement, the TES supplies all the energy required and then at decreasing amounts as before, in the single kiln simulation.

Another variation of the charge and discharge cycle was also considered and is shown in Figure 3.1-14. In this case, the conditions are identical to the previous case except the charge and discharge requirements are out of phase. The TES is charged and discharged during alternate 24 hour periods so the energy is delivered when charging energy is not available. The TES temperature

DI	1	2	3	4	5	6	
HOURS	(8) 16 24	(32) 40 48	(56) 64 72	(80) 88 96	(104) 112 120	(128) 136 144	152 160 168
KILN #1		U	L F		F
KILN #2	U	L F		F	U		
KILN #3	L F		F
KILN #4			U	L F		F

U - UNLOADING

L - LOADING

FIGURE 3.1-12. KILN OPERATION SCHEDULE

FIGURE 3.1-13. MULTIPLE KILN PERFORMANCE CHARACTERISTICS
PROVIDING PREHEAT FROM TES

FIGURE 3.1-14. MULTIPLE KILN PERFORMANCE CHARACTERISTICS
PROVIDING OUT-OF-PHASE PREHEAT FROM TES

profile is shown to reach a higher temperature and discharge to a lower temperature resulting in a wider swing (between 1100°F and 1500°F) than the previous case. The fraction of the demand supplied from the TES is shown on the top of the figure. For the entire cycle, the TES supplies 30% of the demand energy.

3.1.3 SUMMARY OF CALCULATED ENERGY SAVINGS

Recovery and storage of waste heat during kiln firing for subsequent thermal energy demands shows a definite energy savings potential. A summary of the representative energy savings over a firing cycle for the cases discussed are listed in Table 3.1-1. The table includes the total energy available for recovery including both firing and cooldown for the reference kiln, the amount of this energy that can be transferred into the storage system, the total energy demand on the system and the energy delivered to the demand, or energy savings for each application. Of the three potential uses of stored energy applied to a single kiln the kiln preheat provides the highest energy savings, but it also is the largest energy demand. In the brick drying application, nearly all of the demand can be supplied from storage depending on the time phasing of the demand. The difference between the energy recovered and energy savings for drying indicates that the additional energy stored is available for other potential applications. This implies that optimal system operation may include energy delivery to combined demands such as drying and combustion air preheat. The other minor differences between energy recovered and energy savings reflect losses from the system. A TES system applied to a single kiln could supply 41.5% of the total energy requirements for the three uses combined.

The multiple kiln case provides the largest overall energy savings potential. This is also the practical modes for the TES system. An operational strategy of charging and discharging the TES can be developed in a detailed system design for a specific plant operating schedule; the computer program discussed in this section could be used to develop this strategy. In addition, the program can be used as a design tool to provide component sizing for optimizing the system capacities and performance.

TABLE 3.1-1. SUMMARY OF ENERGY SAVINGS FOR CANDIDATE THERMAL ENERGY STORAGE APPLICATIONS

APPLICATION DESCRIPTION	ENERGY AVAIL. FOR RECOVERY MM BTU	ENERGY RECOVERED MM BTU	ENERGY DEMAND MM BTU	ENERGY SAVINGS MM BTU
SINGLE KILN				
- BRICK DRYING	860	210	113	109
- KILN PREHEAT	860	257	849	253
- COMBUSTION AIR PREHEAT	860	193	346	184
MULTI-KILN	969	312	674	296

NOTES: (1) Energy values shown for one cycle.
(2) Sensible heat TES.

3.2 THERMAL ENERGY STORAGE SYSTEM CONCEPTUAL DESIGN

Several alternative thermal energy storage systems were synthesized for the brick kiln waste heat recovery application. These systems - including sensible, latent, and sensible plus latent types - were evaluated and compared. The key result is that for near term applications the sensible heat storage systems using low-cost media such as a dumped (pebble bed) packing are the best performing and most economical selections. Specifically, a rock pebble bed system was determined to have, potentially, the lowest cost, with high heat and temperature recovery. Both the low cost of rock media and the high volumetric heat transfer coefficient of the bed - a result of the high surface area to volume ratio of the individual rocks - are the determining factors in these results. However, development is required to establish a reliable high temperature rock pebble bed design, considering such potential problems as:

- a) media stability and specifications
- b) channeling and packing
- c) pressure drop and for horsepower requirements
- d) thermal ratcheting and structural integrity
- e) manifolding, baffling, and partitioning
- f) media support system design.

Less development would be required for a brick checkerwork design. The conventional brick checkerwork design has slightly higher cost but relatively poor energy and temperature recovery compared to a rock pebble bed. Brick checkerwork costs would be reduced if certain types of substandard brick, such as overfired brick, cracked brick, etc. can be used. Energy and temperature recovery effectiveness would be improved by using higher surface area-to-volume brick forms. This might be achieved using smaller bricks than the standard modular brick and/or employing "new" shapes such as the thin-wall hollow floor tile shapes (Figure 3.2-1). Use of broken brick is also a possibility.

The following sections describe in greater detail the thermal energy storage systems that were synthesized and evaluated, review the evaluation approach, and summarize results.

FIGURE 3.2-1. TYPICAL STRUCTURAL CLAY FLOOR TILE FORMS

3.2.1 CONCEPTUAL DESIGN APPROACH

Table 3.2-1 outlines the approach followed for the System Conceptual Design Task of the Study. Step 1 of the table provided identification of basic process flows for the various operating modes of a brick kiln incorporating thermal energy storage. Functional requirements for thermal energy storage were derived considering these flow diagrams. Step 2 developed state-of-the-art background information for synthesis of alternative systems. Alternative systems synthesized via Step 3 included advanced as well as state-of-the-art concepts. For example, a "thermosyphon pumped spray" concept for thermal energy transport to/from storage, is included. This advanced concept has been explored by General Electric Advanced Energy Programs for solar heating and cooling applications and (independently) is being considered by the U.S. Naval Research Laboratory for solar thermal applications (Reference 5).

TABLE 3.2-1. CONCEPTUAL DESIGN APPROACH

1. Generate process flow diagrams for the different operating modes of a brick kiln with thermal energy storage, for each type of demand served by energy from thermal energy storage (kiln and ware preheating, greenware drying, or combustion air preheating).
2. Review state-of-the-art heat exchange and storage system having potential applicability/adaptability.
3. Synthesize a variety of basically different state-of-the-art and advanced thermal energy storage and heat exchange systems (sensible-solid media, sensible-liquid media, and latent or latent plus sensible; gas-to-media-to-air heat exchange, use of intermediate heat storage (liquid) loops, thermosyphon/pumped spray, etc.).
4. Define a screening procedure for evaluating alternative systems.
5. Estimate costs and develop other comparison data for alternative systems.
6. Compare systems and identify the most promising systems; identify a reference system.
7. Investigate dynamics of the reference system in greater detail.
8. Outline development requirements for the reference system.

A screening procedure was evolved (Step 4) for evaluating and comparing of alternative systems. Cost and other screening data were obtained (Step 5) for inclusion in the comparison matrix for trade-offs and identification of the most promising system concepts and a reference system (Step 6). Dynamics of the thermal energy storage medium for the rock pebble bed (reference system) were simulated (Step 7). Results show the unique characteristic behavior of the system. Development requirements were outlined for the rock pebble bed (Step 8) including development of the media, bed, thermal energy storage unit, system, and brickworks operation levels.

3.2.2 DEMANDS AND PROCESS FLOWS

As was noted in Section 2.0, the most significant energy consuming operations in a brickworks are brick drying and brick firing. Energy (waste heat) recovery from these operations is also most practical, compared to recovery from other operations such as excavation, size reduction, mixing, materials handling, brick forming, packaging, and transportation. Therefore, attention was centered on energy conservation opportunities in the brick firing and drying operations.

Further consideration of these operations through the analysis summarized in Section 3.1.3 indicated that, for periodic and shuttle kilns:

1. The greatest amount of recoverable heat is the heat in the hot flue gases during firing.
2. Large amounts of energy are recoverable after completion of the firing cycle, from the heat stored in the (hot) ware and kiln; this heat is now used either for drying greenware in a nearby dryer, or is exhausted via the flue to the atmosphere and dissipated, during the cooldown phase of the firing cycle.
3. Waste heat recovery from the dryer is impractical, because dryer exhaust is too low in temperature to be of practical value.

Based on these considerations, conceptual designs for energy conservation via thermal energy storage were developed for the following energy inputs to the storage unit:

1. Combustion gas exhausting from kiln during firing, via flue.
2. Heated air exhausting from kiln during cooldown, via flue.

Output from the storage unit was shown to provide the most significant energy savings (Table 3.1-1) when utilized for the following applications.

1. Greenware drying (in some cases, this demand is now served by heated air exhausting from kiln during cooldown directly to dryer).
2. Kiln and ware preheating.

3. Combustion air preheating (recuperation is not now used on the brick kilns to recover flue gas waste heat/preheat combustion air).

Temperature, energy and process interface requirements for these three applications were defined for use in the conceptual design evaluation.

Greenware drying typically requires a large input of heated air at around 300°F, for an average cycle time of 30 hours. Kiln flue (combustion) gas is not commonly used for greenware drying because of product contamination potential and personnel safety considerations.

Kiln and ware preheating refers to that portion of the present firing cycle which can be served without firing by use of recovered and stored waste heat, or waste heat routed directly from a nearby hot kiln.

Combustion air preheating with waste heat can be used to significantly reduce fuel required during the firing cycle. However, combustion air preheating is not used today in the brick industry because:

1. Excess air is introduced at the nozzle for temperature control and increased recirculation.
2. Air volume and, hence, port size is a function of air temperature; air volumes are several times as large for preheated air as for ambient air.
3. High velocity jet burners are not immediately available for use with preheated air.
4. More complex and expensive velocity or mass flow combustion control systems are required with preheated air, compared to simple pressure ratio combustion control systems used with ambient air.
5. Flue gas heat recuperators add initial, operating and maintenance costs to the brick firing operation.

Controlled temperature combustion air preheating - using thermal energy storage - is a particularly attractive way to achieve the significant energy savings possible with combustion air preheating, while at the same time avoiding the practical problems (listed above) encountered with conventional combustion air preheating systems.

Table 3.2-2 summarizes the conceptual system configurations and operating modes discussed above and investigated during this study. Input and output interfaces with the thermal energy storage unit are indicated for each configuration and operating mode.

TABLE 3.2-2.

SYSTEM CONFIGURATIONS AND OPERATING MODES FOR
BRICKWORKS ENERGY CONSERVATION USING THERMAL ENERGY STORAGE

DEMAND SERVED BY TES	FIRING OR COOLING CYCLE	OUTPUT FROM TES	INPUT TO TES
1F. KILN AND WARE PREHEATING	F	✓ (FIRST PART OF CYCLE BEFORE LIGHT-OFF)	✓ (LATTER PART OF CYCLE, AFTER LIGHT-OFF).
1C. KILN AND WARE PREHEATING	C	X	✓
2F. GREENWARE DRYING	F	✓	✓
2C. GREENWARE DRYING	C	X (DIRECT USE OF KILN EXHAUST)	✓
3F. CONTROLLED TEMP. COMBUSTION AIR PREHEATING	F	✓	✓
3C. CONTROLLED TEMP. COMBUSTION AIR PREHEATING	C	X	✓

✓ - YES

X - NO

Once the primary operating modes and process interfaces were defined, schematic diagrams were developed for each of the conceptual approach alternatives. Figure 3.2-2 shows the system schematic indicating conventional kiln and dryer operation. The active fuel and air paths are shown by arrows in the figure. The possibility of using kiln flue gas for the dryer is also noted. The subsequent five figures (3.2-3 to 3.2-7), show all of the alternative operating modes which were considered in evaluating energy savings for each of the conceptual design approaches. The five modes are:

FIGURE	OPERATING MODE	CYCLE
3.2-3	Dryer Heat Supplied by TES; Simultaneous TES charging	Firing
3.2-4	Dryer Heat Demand Supplied by Kiln; Simultaneous TES Charging	Cooldown
3.2-5	Kiln and Ware Preheating from TES	Firing
3.2-6	TES Charging	Cooldown
3.2-7	Controlled Temperature Combustion Air Preheating; TES Charging	Firing

3.2.3 STATE-OF-THE-ART REVIEW

To determine component availability for consideration in the conceptual designs, a brief review of heat exchanger and thermal energy storage unit state-of-the-art was performed. Numerous contacts were made within the industry, including:

1. Eclipse Lookout Division, Eclipse, Inc.
2. American Schack Company, Inc.
3. C-E Air Preheater, Combustion Engineering, Inc.
4. Ajax Electric Company (salt bath heat treating equipment)
5. Robinson Industries, Inc., (high temperature fans).
6. Holcroft Division, Thermo Electron Corporation
7. Granco Equipment
8. Comstock & Wescott, Inc.
9. General Electric Company, Advanced Energy Programs, Evendale (Ohio) Operation.

NOTE: ARROWS INDICATE ACTIVE FLOW PATHS.

CONVENTIONAL INDEPENDENT OPERATION
OF
KILN AND DRYER
(NO THERMAL ENERGY STORAGE)

FIGURE 3.2-2

NOTE: ARROWS INDICATE ACTIVE FLOW PATHS.

DRYER HEAT SUPPLIED BY TES

SIMULTANEOUS TES CHARGING
DURING FIRING CYCLE

FIGURE 3.2-3

DRYER HEAT DEMAND SUPPLIED BY KILN

SIMULTANEOUS TES CHARGING
DURING COOL DOWN

FIGURE 3.2-4

NOTE: ARROWS INDICATE ACTIVE FLOW PATHS.

KILN AND WARE PREHEATING FROM TES

FIGURE 3.2-5

TES CHARGING DURING COOL DOWN

FIGURE 3.2-6

NOTE: ARROWS INDICATE ACTIVE FLOW PATHS.

CONTROLLED TEMPERATURE
COMBUSTION AIR PREHEATING
TES CHARGING DURING FIRING

FIGURE 3.2-7

These contacts, in addition to our own experience, ERDA -sponsored research and development, and literature sources (for example, references #6 through 12) contributed to identification of a variety of applicable/adaptable systems. Table 3.2-3 summarizes a number of diverse heat exchange and storage systems which were considered along with advanced concepts, prior to synthesis of alternative systems for brick kiln application.

Some examples of state-of-the-art, gas-to-solid-to-air heat exchange and storage systems (regenerators) are shown in Figure 3.2-8. An elevator conveyor continuously recirculates the spherical iron baths (pebbles) from the bottom of the Flowing Pebble Bed Regenerator, shown in Figure 3.2-8a to the top of the unit. Most of the energy in the hot combustion gas exhaust is recovered in the top half of the unit, and transferred to influent cold air in the bottom half of the unit.

Figure 3.2-8b shows a packed tower, commonly used for gas absorption, but also used for heat exchange. Examples of some conventional bed packings both dumped and the stacked types, are shown in Figure 3.2-9 (top). These packings are relatively expensive, compared to brick.

Figure 3.2-8c shows, schematically, a reversing regenerator, a type of heat recovery device used in glass and steel production. Refractory brick is often used as the heat storage media (packing). The bricks are stacked in checkerwork patterns, such as those shown in Figure 3.2-9 (bottom).

Figure 3.2-10 shows examples of metallic and ceramic recuperators now in use. The tube-type metallic units are used for influent gas temperature below about 1500°F, ceramic units for higher temperatures. Dilution of hot flue gas with outside air is sometimes done to reduce gas temperature below limits for metallic units. Similar comments apply to the rotary continuous-regenerative air heaters, shown in Figure 3.2-11, except that maximum operating temperature limits for metallic and ceramic rotary regenerators are several hundred degrees lower than for metallic and ceramic recuperators, respectively.

General Electric Advanced Energy Programs, and its predecessor organizations including the Aircraft Nuclear Propulsion Department, Nuclear Materials and Processing Operation and the Space Power and Propulsion Operation, is a leader in the design of liquid metal heat exchangers. "U-tube" and "hockey" stick" tubular units have been designed, built and tested for a number of diverse requirements. Figure 3.2-12 shows, as an example, a liquid metal (NaK)-to-air- heat exchanger designed for an aircraft jet engine application.

Comstock & Wescott, Inc., has designed, built and tested thermal energy storage "household appliances", using a proprietary sodium hydroxide compound as the storage media. Figures 3.2-13 and 3.2-14 show examples of liquid-to-media-to-liquid, and electric heater-to-media-to- air units, respectively. Heat transfer media and mechanical design considerations favor design solutions for application of sensible plus heat of fusion thermal energy storage media which contain the media in small cannisters, tanks, etc., rather than large tanks or pools.

* Hooker Chemicals and Plastics Corporation: Therm-Keep

TABLE 3.2-3 SOME STATE-OF-THE-ART, GAS TO AIR/LIQUID/SOLID
HEAT EXCHANGE AND STORAGE SYSTEMS

HEAT EXCHANGE	HEAT STORAGE
<p><u>GAS-TO-AIR</u></p> <ul style="list-style-type: none"> • Metallic Recuperator • Ceramic Recuperator • Heat Pipe Recuperator • Flowing Pebble Bed Regenerator • Metallic Rotary Regenerator • Ceramic Rotary Regenerator <p><u>GAS-TO-LIQUID</u></p> <ul style="list-style-type: none"> • Gas-to-Molten Salt Heat Exchanger • Liquid Metal-to-Air Heater • Waste Heat Boiler or Water Heater <p><u>GAS-TO-SOLID HEAT EXCHANGER</u></p> <ul style="list-style-type: none"> • Gas-to-Frozen Salt Heat Exchanger • Gas-to-Liquid-to-Frozen Salt Heat Exchange System • Checkerwork Regenerator • Pebble Bed Regenerator 	<ul style="list-style-type: none"> • No • No • Very small • Medium • Very Small • Very Small <ul style="list-style-type: none"> • Can be Large • Can be Large • Can be Large <ul style="list-style-type: none"> • Typically, Small Volumes Aggregated • Some Advantages • Can be Large • Can be Large; Very High Recovery

EXAMPLES OF STATE-OF-THE-ART, GAS-TO-SOLID HEAT EXCHANGE AND STORAGE SYSTEMS

(a) FLOWING PEBBLE BED
REGENERATOR
(BABCOCK AND WILCOX CO.)

(b) PACKED TOWER
(WET TOWER SHOWN, BUT
CAN BE DRY)

(c) REVERSING
REGENERATOR

FIGURE 3.2-5

EXAMPLES OF BED PACKINGS

BERL SADDLE

INTALOX
SADDLE

RASCHIG
RING

LESSING
RING

CROSS PARTITION
RING

SINGLE SPIRAL
RING

DOUBLE-SPIRAL
RING

TRIPLE-SPIRAL
RING

TWO EXAMPLES OF CHECKERWORK CONFIGURATIONS

STANDARD CHECKERWORK
FOR REGENERATORS

SOLID CHIMNEY
CHECKERS

ALSO:

- DUMPED PACKINGS—SCRAP METAL, ROCKS, METAL SPHERES, ETC.
- STACKED PACKINGS—METAL BLOCKS, STANDARD AND NON-STANDARD SHAPES AND SECTIONS

FIGURE 3.2-9

EXAMPLES OF STATE-OF-THE-ART GAS-TO-AIR HEAT EXCHANGERS

BELOW:

CERAMIC REFRACTORY
RECUPERATOR

(STEIN & ATKINSON, LTD.)

ABOVE:

METALLIC GAS-TO-AIR RECUPERATOR
(ECLIPSE LOOKOUT COMPANY)

AIR
PRODUCTS OF COMBUSTION

FIGURE 3.2-10

EXAMPLES OF STATE OF THE ART, GAS-TO-AIR HEAT EXCHANGERS

LJUNGSTROM OR ROTARY
CONTINUOUS-REGENERATIVE
AIR HEATER

(CE AIR PREHEATER CO.)

CERAMIC HONEYCOMB
MATRIX FOR ROTARY
AIR HEATER

(CORNING GLASS WORKS)

FIGURE 3.2-11

EXAMPLES OF STATE OF THE ART GAS-TO-LIQUID HEAT EXCHANGE AND STORAGE SYSTEMS

ENGINE INTEGRATION

ABOVE:

WASTE HEAT BOILER
(ECLIPSE LOOKOUT COMPANY)

HEAT EXCHANGER MODULE

LEFT:

LIQUID METAL-TO-AIR HEAT EXCHANGER
(GE ADVANCED ENERGY PROGRAMS)

FIGURE 3.2-10

"THERM-BANK" WATER HEATER

FIGURE 3.2-13

(HOOKER CHEMICALS &
PLASTICS CORP./
COMSTOCK & WESCOTT, INC.)

DOMESTIC SPACE AIR HEATER

(HOOKER CHEMICALS & PLASTICS CORP./COMSTOCK & WESCOTT, INC.)

FIGURE 3.2-14

3.2.4 REQUIREMENTS AND SCREENING PROCEDURE FOR ALTERNATIVE THERMAL ENERGY STORAGE CONCEPTS

A typical, modern, periodic kiln was identified for reference purposes, and requirements were developed for thermal energy storage systems incorporated into a representative kiln firing cycle. These requirements provided the basis for synthesis of alternative thermal energy storage system conceptual designs. Further a procedure was defined and applied to screen and compare the alternative TES concepts.

3.2.4.1 TES System Design Requirements

Modern, thin-walled periodic kilns for firing brick and structural clay products, and refractories require substantially less fuel per pound of product made than older, heavy-walled beehive kilns. However, the present inventory of periodic kilns in service, including shuttle kilns, consists mostly of older beehive kilns. These older kilns have indefinitely long technical lifetimes with low maintenance, so inventory change has been slow. More recently, fuel shortages have begun to force kiln upgradings, or changes to more efficient kilns.

Thermal energy storage systems for periodic kilns must be adaptable for incorporation in either modern, thin-walled or older, heavy-walled periodic kilns for widespread application/maximum energy conservation. A review of requirements for thermal energy storage units incorporated in energy conservation systems for the respective kiln types indicates that most requirements are more demanding for units operating with modern, thin-walled kilns. This is primarily the result of much higher heat flux inputs to and demands from storage, per unit (BTU) of energy storage capacity. Thus, the modern, thin-walled kiln was selected as the study reference. This reference kiln, and related firing and cooldown cycle data, were then specified in detail for deriving baseline thermal energy storage unit requirements for synthesis, integration and evaluation of alternate system concepts and computer simulations (Section 3.1). Table 3.2-4 gives specifications for the reference kiln.

A set of measured firing data for an actual kiln meeting reference kiln specifications was used for the reference firing cycle. Figure 3.2-15 gives the firing (crown temperature) curve, a curve of combustion gas exhaust temperature at stack-entrance, and the fuel consumption curve, all for the reference firing cycle. Table 3.2-5 provides additional firing cycle data, especially air/fuel ratio and corresponding adiabatic flame temperature data. Cooldown data is given in Table 3.2-6. This cooldown data was calculated, assuming constant air flow equal to maximum air flow during the firing cycle, an exponential decay and exit air temperature at any instant equal to $(.75)^X$ (average ware temperature minus ambient air temperature).

TABLE 3.2-4 . REFERENCE KILN/FIRING CYCLE

● Type of Kiln	- Modern, Thin-Walled Periodic, Top Fired, Sealed, Natural Draft
● Kiln Size	- 36' Diameter X 17' (To Skew Line); Door: 6' W X 14' H.
● Type of Burners	- High Volume, Jet Burners (10), 18" Below Skew Line
● Kiln Construction	- Wall: 1" H Felt (2600°F), 2" Lo Coa Felt (2300°F) 2" Mineral Wool Board, Steel Shell (3/8") Crown: 9" IFB, Steel Shell (3/8")
● Firing Curve	- See Figure 3.2-15
● Cooldown Curve	- See Table 3.2-6
● Heat Balance	- See Table 3.2-7
● Total Kiln Charge	- 208,000 Modular Bricks (4.25 pounds (dry) brick)
● Fuel Consumption Total	- 927 MM BTU/Firing Cycle (900,000 CF of Natural Gas)
● Unit Fuel Consumption	- Firing: 4.3 MCF/1000 Brick

FIRING CURVE FOR REFERENCE KILN

FIGURE 3.2-15

TABLE 3.2-5

REFERENCE KILN FIRING CYCLE DATA

TIME INTO BURN	NO. OF BURNERS	FUEL (GAS)* FLOW cfh X 10 ³	A/F RATIO (V/V)	XSA (%)	O ₂ (%) ²	T ** (°F)
0	10	9.7	37.5	275	15.9	1300
5	10	9.7	37.5	275	15.9	1300
6	10	16.5	22.1	121	12.2	2000
12.5	10	19.4	18.75	87.5	10.5	2250
15	10	24.3	15	50	7.65	2700
32.5	10	24.3	15	50	7.65	2700
38	5	11.7	15	50	7.65	2700
45	5	11.7	15	50	7.65	2700
48	5	8.7	20	100	11.2	2150
52	5	8.7	20	100	11.2	2150

* 1030 BTU/FT³ NATURAL GAS

** ADIABATIC FLAME TEMPERATURE

TABLE 3.2-6 . REFERENCE KILN COOLDOWN CYCLE DATA (SYNTHESIZED)

TIME (HRS.)	WARE TEMPERATURE (°F)	AIR TEMPERATURE (°F)	BTU'S STORED IN WARE (70°F REFERENCE ENTHALPY)
0	1900	1450	409,000
5	1717	1313	367,000
10	1515	1161	321,000
15	1339	1029	281,000
20	1184	913	246,500
25	1048	811	216,000
30	930	722	189,500
32	887	690	180,000

KILN DOOR OPENED 32 HOURS AFTER START OF COOLDOWN

NOTE: CONSTANT AIR FLOW OF 383,000 SCFH THROUGHOUT COOLDOWN

Table 3.2-7 presents the heat balance for the reference kiln/cycle, integrated for the complete firing cycle, before cooldown. Each heat loss or storage term was calculated in detail. Reference 15 was used as the basis for calculating heat stored in the ware. Heat lost through and stored in the kiln envelope was estimated using data from Reference 16. Addition of the results for each term gives a total heat consumption value very close to the calculated total heat available from the fuel consumed during the cycle (Table 3.1-1). It is important to note that there is very little heat stored in the envelope of a modern thin-walled kiln. The heat loss through the envelope is significantly lower than the loss in heavy-walled kilns. Most of the energy from the fuel consumed during firing goes into the ware (44.7%), or up the stack (44.5%).

In addition to the reference kiln and firing and cooldown cycle definition, a requirement for capability to support integrated multi-kiln operations was specified. For multi-kiln operations, the thermal energy storage unit must be capable of simultaneously accepting a charging input, and providing a discharging output, without interference.

Thermal energy storage unit utilization (energy turn-around) is greater per unit of storage capacity for multi-kiln than for single kiln operation. Therefore, the investment for storage units would be less per unit of energy recovered/utilized for multi-kiln installations.

3.2.4.2 Screening Procedure

A 7-step procedure was followed for development of cost and other screening data for the alternate thermal energy storage devices which were later synthesized and evaluated. Table 3.2-8 summarizes this 7-step procedure. The first step is the definition of the flue gas energy profile as a function of entering flue gas temperature. Figure 3.2-16 gives the energy profile for the reference kiln/firing cycle. Firing temperature, hence flue gas temperature, monotonically increases throughout the firing cycle. Maximum temperature in the charged thermal energy storage unit can potentially approach maximum flue gas temperature.

A single-kiln operating scenario was assumed for comparison. Operating temperature limits - maximum and minimum - were specified (in cases where material properties or design imposed limits), or estimated, for cyclic operation of the thermal energy storage unit (Step 2). The temperature profile of the storage media, in response to the imposed flue gas energy profile, was calculated and plotted on the same graph as the flue gas energy profile. Figure 3.2-16 gives an example for a brick checkerwork (thermal energy storage media) system.

Next, using the energy and temperature profile data, the energy recovered by the TES was calculated (Step 4). An effectiveness of .7 was assumed (Reference 2) for the stack heat exchanger. The resulting percent of the available waste heat recoverable for 7 candidate TES systems is summarized in Table 3.2-8A. Knowing the amount of recovered energy which must be accommodated, and acceptable media temperature limits, the weight, volume and

TABLE 3.2-7 HEAT BALANCE FOR REFERENCE KILN/CYCLE AT END OF FIRING PERIOD

	BTU	%
1. SENSIBLE HEAT LOST THROUGH FLUE		
• BELOW 600°F - 183,000,000/19.8%		
• ABOVE 600°F - 229,000,000/24.7%	412,000,000	44.5
2. HEAT INTO WARE		
• STORED IN WARE - 409,000,000/44.1%		
• LATENT HEAT OF H ₂ O - 5,500,000/.6% EVAPORATED	414,500,000	44.7
3. HEAT LOST THROUGH ENVELOPE		
• WALLS - 35,500,000/3.8%		
• CROWN - 16,000,000/1.7%		
• FLOOR - 16,000,000/1.7%	67,500,000	7.2
4. HEAT STORED IN ENVELOPE		
• WALLS - 3,000,000/.3%		
• CROWN - 11,000,000/1.2%		
• FLOOR - 11,000,000/1.1%	25,000,000	2.6
5. INCOMPLETE COMBUSTION (ASSUME 1%)	9,500,000	1.0
6. UNACCOUNTED FOR, AND ERRORS	(1,500,000)	(.1)
TOTAL = TOTAL MEASURED HEAT AVAILABLE FROM FUEL (GAS) CONSUMED. NOTE: ASSUMES GAS VOLUME CORRECT AS METERED, GAS CALORIC VALUE CORRECT AS SPECIFIED.	927,000,000	100

TABLE 3.2-8 . PROCEDURE FOR DEVELOPMENT OF SCREENING DATA
FOR ALTERNATE TES UNIT CONCEPTS

1. Define percent increments of flue gas waste heat energy as a function of entering flue gas temperature.
2. Define operating temperature limits of various alternate concepts.
3. Define temperature response of media operating between limits, to flue gas energy profile.
4. Calculate energy recovered by TES.
5. Determine weights, volumes, dimensions of media and enclosure required.
6. Estimate total costs for TES unit.
7. Calculate unit cost* (Dollars per million BTU's capacity) for Thermal Energy Storage Unit.

$$\text{* Unit Cost} = \frac{\text{Total Installed Cost for Tes Unit}}{\text{Energy Stored Between Operating Temperature Limits (Capacity in Million BTU's)}}$$

NOTE: Unit Cost* of TES tends to be overstated by this procedure, since inputs to TES and outputs from TES can occur simultaneously in service decreasing physical size and capacity requirements.

SENSIBLE HEAT STORAGE IN BRICK CHECKERWORK

(REFERENCE KILN CYCLE)

FIGURE 3.2-16

TABLE 3.2-8A. NOMINAL RECOVERABLE WASTE HEAT AVAILABLE
FOR CANDIDATE TES SYSTEMS

TES CONCEPT	OPERATING TEMPERATURE RANGE	PERCENT OF AVAILABLE WASTE HEAT RECOVERED
BRICK CHECKERWORK	400-900°F	41.5
IRON PEBBLE BED	400-900°F	41.5
ROCK PEBBLE BED	400-900°F	41.5
LATENT/SENSIBLE NaOH	550-800°F	39.3
NaK BATH/IRON CHECKERWORK	400-1100°F	38
NaK POOL/IRON CHECKERWORK	400-1100°F	38
IRON, DOWTHERM POOL	400-650°F	52.7

dimensions of the thermal energy storage media and its enclosure were determined (Step 5),

Costs were estimated (Step 6) for the thermal energy storage unit sized via Step 5. This cost, divided by the energy recovered/stored between operating temperature limits (Step 4), yielded the unit cost for the storage unit in terms of dollars per BTU of capacity (Step 7).

3.2.5 SYNTHESIS OF ALTERNATIVE THERMAL ENERGY STORAGE SYSTEMS AND COSTS

The initial approach to synthesis of alternative thermal energy storage devices was to identify one or more promising possibilities in each of the following four categories:

1. Storage of thermal energy in solid media.
2. Storage of thermal energy in solid-liquid media (phase change material).
3. Storage of thermal energy in liquid media.
4. Advanced concepts.

The key criteria applied to the generation of alternative concepts were:

1. Low Cost.
 - a. Low initial cost (\$ installed cost for thermal energy storage unit BTU's recovered per cycle between operating temperature limits).
 - b. Low operating and maintenance cost.
2. Thermal Performance
 - a. High recovery of available waste heat.
 - b. Small degradation of temperature level of waste heat delivered from storage, as compared to temperature level of flue gas waste heat source.

Both state-of-the-art and advanced concepts were included for consideration. Other factors such as development requirements, safety, ease of introduction/acceptance by industry, and differences in impact on operations were considered after concept synthesis and cost and performance evaluation, during comparison of alternative concepts (Section 3.2.6).

Preliminary analysis indicated that liquid storage media for use at the range of operating and non-operating temperatures required were too expensive (cost per unit of energy stored) to be used for bulk energy storage. Therefore, a lower cost solid matrix - displacing higher cost liquid - was incorporated into the media for all "liquid" systems investigated for this study. Table 3.2-9 classifies and identifies the particular thermal energy storage concepts synthesized and investigated.

Costs were estimated for each type of thermal energy storage unit, sized according to the procedure defined in Section 3.2.4. Unit prices for materials used in the different types of thermal energy storage units were obtained from various sources. Results are given in Table 3.2-10; prices for Items 1-5 are August, 1976 list prices; prices for items 6-8 are from "Engineering News Record" (July and August 1976 issues) prices for Item 9 - sodium hydroxide - are from sources indicated in the Table. The installed cost of steel tanks and pressure vessels is taken from Vilbrandt and Dryden (reference 3.2-13), pp. 216 and 217. Figure 3.2-17 gives the installed cost for low carbon steel pressure vessels, as a function of volume and operating pressure, and Figure 3.2-18 gives the installed cost as a function of volume of storage tanks constructed of various materials, including low carbon steel and stainless steel, all based on an ENR index of 750. The current (August, 1976) ENR index is

TABLE 3.2-9 . TES UNIT CONCEPTS FOR BRICK KILN APPLICATION

- Storage of thermal energy in solid media (sensible heat storage)
 - Iron Pebble Bed
 - Rock Pebble Bed
 - Brick Checkerwork
- Storage of thermal energy in solid-liquid media (latent plus sensible heat storage)
 - NaOH in Drums
- Storage of thermal energy in liquid media with solid matrix (sensible heat storage)
 - NaK-78 Bath with Iron Matrix
 - NaK-78 Pool with Iron Matrix
- Storage of thermal energy in solid media (sensible heat storage), energy transport to storage via thermosyphon/from storage via pumped spray
 - Dowtherm Pool, Iron Matrix

TABLE 3.2-10 UNIT PRICES FOR SELECTED THERMAL ENERGY STORAGE MEDIA
AND HEAT TRANSPORT FLUIDS

MATERIAL	UNIT PRICE	REMARKS
1. HITEC	• \$.34/POUND*	• QUANTITIES OF 30,000 POUNDS AND OVER, F.O.B. ABBEVILLE, LA.
	• \$.30/POUND*	• QUANTITIES OF 40,000 POUNDS AND OVER, F.O.B. GIBSTOWN, N.J.
2. THERMINOL 66	• \$6.10/GALLON **	• QUANTITIES OF 60 (55 GA.) DRUMS AND OVER
3. THERMINOL 88	• \$.65/POUND ***	• QUANTITIES OF 300 (75 LB.) BAGS AND OVER
4. DOWTHERM (ANY)****	• \$6-\$7/GALLON	
5. NaK-78 OR	• \$1.95/POUND	• QUANTITIES OF 10,000 POUNDS AND OVER
NaK-56	• \$1.60/POUND	• QUANTITIES OF 50,000 POUNDS AND OVER
6. COMMON BRICK	• \$89/1000	• TRUCKLOAD QUANTITIES
7. STRUCTURAL STEEL	• \$13.55/100 POUNDS	• BASE
8. CRUSHED STONE, 1 1/2"	• \$4.26/TON	• CARLOAD QUANTITIES
9. NaOH	• \$.25/POUND	} • GE TIS 76CRD041
	• \$.125-\$.15/POUND AS CAUSTIC	
	• \$.06/POUND	• COMSTOCK & WESCOTT, DEC. '73
	• \$.24/POUND	• SANDIA SAND75-8063

* ABOUT 110 PCF OR 15 POUNDS/GALLON AT 750°F

** 8.35 POUNDS/GALLON AT 75°F

*** 7.5 POUNDS/GALLON AT 550°F

**** DOWTHERM A: 66.7 PCF @ 60°F

**** NaK-56 : 51.35 PCF @ 800°F; NaK-78 : 48.3 PCF @ 800°F

INSTALLED COST FACTORS FOR STEEL TANKS AND PRESSURE VESSELS

FIGURE 3.2-17

FIGURE 3.2-18

NOTES:

1. ENR = 2445, AUGUST, 1976

2. $\frac{2445}{750} = 3.26$

2445, so installed costs were estimated using $\frac{2445}{750} = 3.26$

times the installed costs indicated on the Figures. Stainless steel pressure vessel costs were estimated using, as a baseline, costs for low carbon steel tanks. (Per Figure 3.2-17, adjusted by ENR ratio). Low carbon steel tank costs were then multiplied by the ratio of costs for stainless steel vs. low carbon steel tanks, taken from Figure 3.2-18, to yield estimated costs for stainless steel pressure vessels.

Reference 14 on thin-walled kiln construction and costs, was used to provide baseline data for estimation of insulated thermal energy storage unit enclosure costs. The baseline estimates were updated to current costs by using the ratio of ENR indices for the respective time periods, and multiplying by a complexity factor to account for the differences in thermal energy storage unit vs. kiln enclosure requirements.

Cost estimates for the different thermal energy storage units do not include costs for recuperators, liquid heat transport loops from recuperators to storage, and/or to served load heat exchangers. That is, cost estimates are limited to costs of the thermal energy storage units including internal pumps and piping, housing, heat exchangers inside the unit, etc.

Using these cost groundrules, the following subsections present alternative conceptual designs and associated costs for each of the four prime TES categories of solid media, phase change media, liquid media, and advanced concepts.

3.2.5.1 Thermal Energy Storage in Solid Media

Three different solid media were investigated:

1. Brick checkerwork.
2. Iron pebble bed.
3. Rock pebble bed.

Figure 3.2-19 shows incorporation of a multi-compartment solid media thermal energy storage unit into the kiln schematic. Multiple compartments in the thermal energy storage unit permit simultaneous charging from multiple sources and discharging to multiple demands. Differences in characteristics and behavior of the respective solid media affect sizing and design of the thermal energy storage unit, but the basic scheme for incorporation is similar in all cases.

Tables 3.2-11, 12, and 13, summarize key features (operating temperature range, BTU capacity, media weight, and enclosure volume for the thermal energy storage unit) and cost estimates for the brick, iron and rock solid media, respectively. In each case, the available waste heat for TES recovery was taken as 412 mm BTU, the flue sensible heat loss from Table 3.2-7.

The cost estimated for the rock pebble bed is slightly lower than the cost estimated for the brick checkerwork unit. The unit price data used for rocks was double (2X) the current price given by Engineering News Record for course aggregate; it is assumed that tighter specifications for rocks

ENERGY CONSERVATION SYSTEM
EMPLOYING STORAGE OF THERMAL ENERGY
IN SOLID MEDIA
(SENSIBLE HEAT STORAGE)

TO USERS *

- KILN PREHEATING
- COMBUSTION AIR PREHEATING
- BRICK DRYING

- TES:
- BRICK, IRON OR ROCK CHECKERWORK OR PEBBLE BED
 - IFB, BLANKET LINED

FIGURE 3.2-19

TABLE 3.2-11 COST OF TES UNIT

SENSIBLE HEAT STORAGE IN BRICK CHECKERWORKKEY FEATURES

- OPERATING TEMPERATURE RANGE ASSUMED 400°F TO 900°F (EFFECTIVE AVERAGE TEMPS.)
- BTU'S RECOVERED DURING FIRING - 171 MILLION (41.5% OF AVAILABLE WASTE HEAT)*
- WEIGHT OF BRICKS REQUIRED - 731 TONS
- VOLUME OF TES ENCLOSURE - 30,000 FT³ (E.G., 40' X 30' X 25' HIGH)

COST ESTIMATE

● BRICKS, 6 POUND - 244,000 @ 9¢	\$ 22,000
● ENCLOSURE AND UPPER PLENUM - 5900 FT ² @ \$6/FT ²	35,000
● FANS AND MOTORS, DAMPERS, DUCTS, SHORT STACK, ACCESSORIES.	10,000
● EARTHWORK, FLUES, LOWER PLENUM AND BAFFLES, FOUNDATION, AND FLOOR (1200 FT ²)	14,500
	<hr/>
	\$ 81,500

UNIT COST

$$\frac{\$81,500}{171 \text{ MM}} = \$477/\text{MILLION BTU'S CAPACITY}$$

* Taken from analysis integrating difference between two curves in Figure 3.2-16, with a 70 percent heat recovery efficiency.

TABLE 3.2-12 COST OF TES UNIT

SENSIBLE HEAT STORAGE IN IRON PEBBLE BED

KEY FEATURES

- OPERATING TEMPERATURE RANGE ASSUMED - 400°F TO 900°F (EFFECTIVE AVERAGE TEMPS.)
- BTU'S RECOVERED DURING FIRING - 171 MILLION (41.5% OF AVAILABLE WASTE HEAT)*
- WEIGHT OF CAST IRON BALLS REQUIRED - 1900 TONS
- VOLUME OF TES ENCLOSURE - 15000 FT³ (B.G., 30' X 30' X 16 1/2' HIGH)

COST ESTIMATE

● IRON - 1900 T @ \$300/T	\$ 570,000	(SEE NOTE BELOW)
● ENCLOSURE AND UPPER PLENUM - 3780 FT ² @ \$9/FT ²	34,000	
● FANS AND MOTORS, DAMPERS, DUCTS, SHORT STACK, ACCESSORIES	10,000	
● EARTHWORK, FLUES, LOWER PLENUM AND BAFFLES, FOUNDATION AND FLOOR - (900 FT ²)	16,000	
	<hr/>	
	\$ 630,000	

UNIT COST

$$\frac{\$630,000}{171 \text{ MM}} = \$3684 \text{ MILLION BTU'S CAPACITY}$$

NOTE: SCRAP IRON, IF SUITABLE, MIGHT REDUCE THIS TO AROUND \$100,000 (SCRAP IRON APPROX. \$50/T)

* Table 3.2-8A

TABLE 3.2-13

COST OF TES UNIT

SENSIBLE HEAT STORAGE IN ROCKKEY FEATURES

- OPERATING TEMPERATURE RANGE ASSUMED - 400°F TO 900°F (EFFECTIVE AVERAGE TEMPS.)
- BTU'S RECOVERED - 171 MILLION (41.5% OF AVAILABLE WASTE HEAT) *
- WEIGHT OF ROCKS REQUIRED - 910 TONS
- VOLUME OF TES ENCLOSURE - 25,000 FT³ (E.G., 25' X 40' X 25' HIGH)

COST ESTIMATE

● ROCKS - 910 T @ \$8.50/T	\$ 8,000
● ENCLOSURE AND UPPER PLENUM - 4250 FT ² @ \$9/FT ²	38,000
● FANS AND MOTORS, DAMPERS, DUCTS, SHORT STACK, ACCESSORIES	10,000
● EARTHWORK, FLUES, LOWER PLENUM AND BAFFLES, FOUNDATION AND FLOOR (1000 FT ²)	12,000
	<hr/>
	\$ 68,000

UNIT COST

$$\frac{\$68,000}{171 \text{ MM}} \longrightarrow \$397/\text{MILLION BTU'S CAPACITY}$$

* Table 3.2-8A

used as thermal energy storage media will cause this magnitude of price change. For example, selected rock such as granite (igneous rock) may be required, along with more uniform sorting (size).

The unit price used for checkerwork brick is the current Engineering News Record price for common brick. More refractory brick might be required in some applications. Use of seconds or lower quality brick, such as over-fired brick, cracked brick, or possibly broken brick, would result in lower cost for the brick checkerwork thermal energy storage unit. Media cost is not the major cost item for either the rock pebble bed or brick checkerwork units.

The major differences affecting selection of the rock pebble bed vs. the brick checkerwork are:

1. The brick checkerwork is a stacked packing type; it is not susceptible to thermal ratcheting and does not develop pressure/pressure buildup on the container sidewalls; it does not pack down with thermal cycling in operational use; it avoids flow channeling problems by having defined flow paths of more or less tightly controlled dimensions.
2. The rock pebble bed has an extremely high surface area per unit volume of bed; this leads to a characteristically different type of behavior for the bed - discussed more in Section 3.2.7 - which gives high waste heat recovery/delivery from storage at minimum degradation of temperature.

Reference surface area per unit volume and volumetric heat transfer coefficient data for 1 mm diameter particles is provided by Table 3.2-14. . It is possible to improve the volumetric heat transfer coefficient of conventional brick checkerwork from, say, 15 BTU/Ft³- Hr./°F to several times this figure by use of thinner bricks. The volumetric heat transfer coefficient for small pebbles would still be an order of magnitude greater than the value for brick checkerwork.

Potentially, if scrap iron can be used as the packing, the iron pebble bed could approach being competitive in cost with the brick or rock beds. Current price of No. 1 Heavy Melting is \$50/T - \$90/T (American "Metal Market/Metalworking News", 8/23/76). Machine shop turnings are even less expensive, running - depending on quality and city - mostly around \$20/T - \$35/T, compared to \$300/T used in this Study for spherical iron packing media. Channeling problems and uncertain flow/pressure drop characteristics are anticipated with use of assorted scrap iron and steel, including cutoff from structural shapes.

3.2.5.2 Thermal Energy Storage in Solid-Liquid Phase Change Media

Use of a thermal energy storage media material which undergoes a phase change at a desired temperature offers a number of potential advantages in thermal energy storage unit design and its applications and utilization. In cases where operating temperature range of the storage media must be limited to small excursions, a more compact unit is possible than with sensible heat storage in a media of comparable density. Also, with latent heat storage,

TYPICAL OVERALL CONDUCTANCE VALUES FOR RECUPERATORSTYPE OF RECUPERATOR $\frac{U}{\text{BTU PER (SQ. FT. - HR. - }^{\circ}\text{F)}}$

CLAY TILES	0.4 TO 1.7
SILICON CARBIDE WITH VORTEX COREBUSTERS	3 TO 5
METALLIC, WITH LOW AIR VELOCITY	2 TO 3.5
METALLIC, WITH HIGH AIR VELOCITY	3.5 TO 5.5
METALLIC, WITH HIGH AIR VELOCITY AND WITH PROJECTIONS OR FINS WHICH ARE NOT INCLUDED IN (CALCULATION) HEATING SURFACE	7 TO 10

SOURCE: TRINKS (REFERENCE 7)

HEAT TRANSFER SURFACE PER CUBIC FOOT OF VOLUMEMEDIASQ. FT.

PEBBLES, 5/16 IN. DIAMETER	135.5
PEBBLES, 1/2 IN. DIAMETER	86.5
STEEL TUBES, 2 1/2 IN. O.D. (3 1/4 BY 3 1/4 IN. ON CENTERS)	9.0
REGENERATOR CHECKERBRICK	3.0 - 8.0

SOURCE: NORTON (REFERENCE 34)

EFFECTIVE FILM COEFFICIENTS FOR PEBBLE BEDMATERIAL $\frac{h_v}{\text{BTU PER (CU. FT. - HR. - }^{\circ}\text{F)}}$

IRON ORES	406-1200
LIMESTONE	460
COKE	347
BLAST-FURNACE CHARGE	260
COAL	400
FIREBRICK	534
IRON BALLS	668
GRAVEL	399
LEAD, GLASS, STEEL SPHERES*	

* DATA FOR .0394 IN PARTICLE DIAMETERS,
AIR FLOW 50SCFM/FT² MIN., 200°F INLET
AIR TEMPERATURE, NORMAL VOIDS.

SOURCE: LOF AND HAWLEY (REFERENCE 32)

provisions for modulation of output temperature might be unnecessary, since output can be at nearly constant temperature.

A number of phase change materials were considered in this study. References 17 through 23 give a partial list of literature consulted.

Preliminary analysis indicated that the cost of thermal energy storage only utilizing the latent enthalpy difference at phase change temperature, is too high to be competitive for the brick kiln application. Use of latent plus sensible thermal energy storage over a wider range of operating temperatures is potentially competitive, however. The phase change media material most developed for thermal energy storage, a sodium hydroxide based compound, is relatively inexpensive and non-corrosive. It can be contained in low carbon steel containers if moisture is excluded. This sodium hydroxide media material was used for reference in this study.

Figure 3.2-20 shows the basic scheme for incorporating the sodium hydroxide thermal energy storage unit. A gas-to-liquid heat exchanger is used to transfer flue gas waste heat to a liquid loop. Heat is transferred from the liquid loop either:

1. directly to air which is heated to supply a coincident demand, via a liquid-to-air heat exchanger.
2. to the thermal energy storage media via a heat exchanger in each individual container of thermal energy storage media.

These same heat exchangers are used for transferring heat from storage to supply demands which cannot be supplied directly without storage.

Heat transfer to/from a solid-liquid media is complicated by the fact that the heat exchange scheme must adequately transfer heat to/from the media in solid and/or liquid states. A single coil immersed in a large unstirred pool will not give satisfactory results because:

1. Frozen salt on the coils will inhibit heat transfer during discharging; the salt will tend to increase in thickness progressively with discharging.
2. Heat transfer to the (solid) media during charging may be limited initially by poor thermal contact between the coil and the media, a result of media shrinkage during freezing.
- 2a. Alternatively, mechanical damage may occur to the heat exchange coil, supports, tubing, or container as a result of media expansion during freezing.
3. Heat exchange after initial melting during charging is convection-controlled/limited.

One solution to these problems is to place the media in a number of small containers, each with a heat exchange coil, to reduce the scale of factors

ENERGY CONSERVATION SYSTEM
EMPLOYING STORAGE OF THERMAL ENERGY
IN SOLID-LIQUID MEDIA

(LATENT PLUS SENSIBLE HEAT STORAGE)

TO USERS *

- KILN PREHEAT
- COMBUSTION AIR PREHEAT
- BRICK DRYING

LIQUID LOOP: HITEC

TES:

- MODULAR THERMAL ENERGY STORAGE MEDIA CONTAINER, NaOH MEDIA
- STEEL SHELL, INSULATED, UNPRESSURIZED, AND SEALED

FIGURE 3.2-20

which cause problems in large scale. Work at the University of Pennsylvania (reference 24) and by Comstock and Wascott, Inc. (reference 21 through 23) have demonstrated this approach. Figure 3.2-21 is a concept drawing of a modular thermal energy unit using a 55 gallon drum as the container. A standard low carbon steel drum, which sells for about \$20, might be suitable with minor modification for use at temperatures up to around 800°F. Above this temperature drop off of strength of low carbon steel and deformation of carbon steel from residual cold rolling stresses, probably requires use of a stainless steel drum. A stainless steel drum sells for over \$200, so its use is not economical in spite of the wider operating temperature range possible. Therefore, a maximum operating temperature limit of 800°F was specified for evaluation purposes.

Table 3.2-15 gives key features and a cost estimate for an 1100 drum thermal energy storage unit for application to the reference brick kiln/cycle. A unit price of 15¢ per pound was used for the sodium hydroxide compound, a somewhat higher figure than given by Comstock & Wascott, but lower than estimates by Sandia (reference 18) and, independently, General Electric's Corporate Research and Development Laboratory (reference 19), see Table 3.2-10. Compared to the uncertainty in this factor, the other cost items offer less significant potential for cost reduction.

The minimum operating temperature assumed for purposes of evaluation of the sodium hydroxide unit was 550°F, the temperature of the $S \rightarrow L$ solid state transformation (70 BTU/lb). (Melting occurs at 604°F (70 BTU/lb)). Below 550°F, heat transfer to/from the solid media is more difficult due to additional shrinkage.

3.2.5.3 Thermal Energy Storage in Liquid/Solid Matrix Media

Liquid storage media can be also used as the heat transport fluid from the gas-to-liquid recuperators taking waste heat from flue gases and to the liquid-to-air heat exchangers delivering heat to service loads. This eliminates the need for heat exchangers in the thermal energy storage unit. Stratified storage techniques can be employed which maintain thermoclines to minimize temperature degradation of stored energy. These factors suggest that liquid storage media are especially well suited for thermal energy storage application, assuming that a working fluid having the following characteristics is available:

1. Low cost.
2. High specific heat.
3. High density.
4. High thermal conductivity.
5. Low viscosity.
6. High operating temperature without degradation.

CONCEPT OF MODULAR THERMAL ENERGY STORAGE
MEDIA CONTAINER FOR SOLID-LIQUID STORAGE MEDIA

FIGURE 3.2-21

TABLE 3.2-15

COST OF TES UNIT

LATENT AND SENSIBLE HEAT STORAGE IN N_2OH KEY FEATURES

- OPERATING TEMPERATURE RANGE ASSUMED - 550°F TO 800°F (UNIFORM TEMPS.)
- BTU'S RECOVERED DURING FIRING - 162 MILLION (39.3% OF AVAILABLE WASTE HEAT)*
- WEIGHT OF N_2OH REQUIRED - 347 TONS
- VOLUME OF TES ENCLOSURE (AROUND 1100 - 55 GA. DRUMS) - 25,800 FT³
(43' DIA. X 17' HIGH)

COST ESTIMATE

● DRUMS, STANDARD 55 GA. STEEL - 1100 @ \$20 EA.	\$ 22,000
● COILS, HEAT TRANSFER - 1100 @ \$10 EA.	11,000
● N_2OH - 347T @ \$300/T (\$.15 LB)	104,000
● PUMPS AND MOTORS, VALVES AND PIPING, VENT LINE, ACCESSORIES	20,000
● ENCLOSURE (3800 FT ² X \$3/FT ²)	11,000
● FOUNDATION AND FLOOR (1500 FT ²)	9,000
	<hr/>
	\$ 177,000

UNIT COST

$$\frac{\$177,000}{162 \text{ M.}} \rightarrow \$1092/\text{MILLION BTU'S CAPACITY}$$

* Table 3.2-8A

6. Liquid at ambient temperature.
7. Low vapor pressure at operating temperature.
8. Stable in presence of air, moisture, container and other materials
9. Non-corrosive.
10. Safe, easily handled.

For brick kiln applications, the maximum operating temperature desired is over 1000°F. This rules out all organic working fluids. Hitec (DuPont/Coastal Chemical), an inorganic salt* used for heat transfer at temperatures near 1000°F, can be maintained in the liquid state down to ambient temperature using a proprietary (American Hydrotherm Corporation) water dilution technique (reference 25). . Packaged systems can be provided for implementation of the dilution system in a process heat transfer system application. Applications to date have been for "continuous" processes which run for weeks or months without shutdown. Addition of dilution water on shutdown, and boil-off of water on start-up each require about 8-10 hours. These times are potentially compatible with the brick firing and cooldown process. Hitec costs 30¢/lb in large quantities.

NaK-78, a eutectic alloy of sodium and potassium, is liquid at ambient temperature and can be used at high temperature without high vapor pressure (normal boiling point is 1440°F). NaK-78 costs \$1.60/lb in large quantities..

Both NaK and Hitec must be "covered" by an inert gas to prevent degradation from exposure to the atmosphere at high temperature. NaK also presents a hazard since it will react violently with water. Low carbon steel tanks and piping cannot be used with NaK or Hitec above 850°F; stainless steel is commonly used with these heat transfer media. Reference 26 provides more detailed information on liquid metal molten salt and other heat transfer media.

Figure 3.2-22 shows the scheme for integration of a thermal energy storage unit using a low carbon iron matrix in NaK-78 liquid metal media. Use of the iron media reduces costs total media cost by displacing expensive NaK with iron, though not on a pound-for-pound basis (specific heat differences). The scheme for incorporation of a Hitec molten salt thermal energy storage system would be similar, but would include provisions for water dilution and boil-off.

Table 3.2-16 gives key features and a cost estimate for the liquid metal thermal energy storage unit. Cost for the molten salt unit might be in the vicinity of \$600,000 (compared to \$1,200,000 for the liquid metal unit) if the salt dilution technique can be demonstrated to be practical.

Cost of either the liquid metal or the molten salt thermal energy storage unit can be reduced by reducing the inventory of liquid media. Figure 3.2-23 shows a scheme in which a pool of liquid media replaces the bath of liquid media. The heat capacity reduction from the liquid media inventory difference is compensated by increased inventory of iron in the matrix.

*Potassium nitrate 53%, sodium nitrite 40%, and sodium nitrate 7%.

ENERGY CONSERVATION SYSTEM
EMPLOYING STORAGE OF THERMAL ENERGY
IN SOLID AND LIQUID MEDIA
(SENSIBLE HEAT STORAGE)

TO USER *

- KILN PREHEATING
- COMBUSTION AIR PREHEATING
- BRICK DRYING

LIQUID LOOP AND BATH: NAK-78

TES: • MATRIX OF LOW C IRON
CHECKERWORK OR PEBBLE BED IN
NAK-78 BATH FOR INCREASED
CAPACITY/REDUCED COST

- STAINLESS STEEL SHELL, LOW
PRESSURE, INSULATED, AND SEALED

FIGURE 3.2-22

TABLE 3.2-16. COST OF TES UNIT

SENSIBLE HEAT STORAGE IN NaK BATH/IRON CHECKERWORKKEY FEATURES

- OPERATING TEMPERATURE RANGE ASSUMED 400°F TO 1100°F
- BTU'S RECOVERED DURING FIRING - 156.5 MILLION (38% OF AVAILABLE WASTE HEAT) *
- WEIGHT OF NaK-78 AND IRON REQUIRED - 1129 TONS
(110 TONS NaK-78, 1019 TONS OF IRON)
- VOLUME OF TES ENCLOSURE - 11000 FT³ (E.G., VERT. CYL. TANK, 25' HIGH X 12' RAD.)

COST ESTIMATE

• NaK-78 - 220,000 POUNDS @ \$1.60/POUND	\$ 352,000
• IRON - 1019 TONS @ \$300/TON	306,000
• TANK - 82,500 GALLON CRES	511,000
• SUMP FOR 220,000 POUNDS OF NaK-78	(NOT INCLUDED)
• PUMPS AND MOTORS, HEADERS, INSTALLED VALVES AND PIPING, PURIFICATION, ACCESSORIES	20,000
• EARTHWORK, FOUNDATION AND SUPPORT BED (450 FT ²)	<u>11,500</u>
	\$1,200,000

UNIT COST

$$\frac{\$1,200,000}{156.5 \text{ MM}} \longrightarrow \$7668/\text{MILLION BTU'S CAPACITY}$$

* Table 3.2-8A.

11-75

- KILN PREHEATING
- COMBUSTION AIR PREHEATING
- BRICK DRYING

TES: 0 MATRIX OF IRON CHECKERWORK
OR PEBBLE BED IN OR OVER NAK-78
POOL

FIGURE 3.2-23

The net result of this design (see Table 3.2-17) is a reduction of nearly \$200,000 for the liquid metal unit; reduction for the molten salt unit would be only around 1.3 as much. One disadvantage of the pool vs. the bath is that flow during charging as well as discharging is in the same direction (down). This results in dissipation of thermal stratification benefits.

Another possible source of cost reduction is via use of scrap iron for the matrix.

3.2.5.4 Thermal Energy Storage in Solid Media with Vapor/Liquid Heat Transfer to/from Media

A concept was developed, based on previous work on thermal energy storage techniques for solar heating and cooling systems, which eliminates the performance handicap in liquid pool/solid matrix systems caused by same direction flow for both charging and discharging. This concept employs a volatile liquid in the pool. Charging of the solid storage media is accomplished by boiling the pool liquid and condensing the vapor on the solid matrix. The condensing zone would move upward progressively as the matrix would be heated from the bottom up.

On discharging, the fluid to be heated (by stored heat) would be sprayed down on the matrix from the top of the vessel, and would trickle down the matrix into the pool. Hot liquid would be drawn from the pool on demand and used to heating loads. The matrix would be discharged progressively from the top down, and degradation of temperature of the stored energy would be minimized. A similar concept has been developed by the Naval Research Laboratory (reference 5).

Figure 3.2-24 illustrates the concept, and Table 3.2-18 gives features and costs for a thermal energy storage unit. The high cost item by far is cost of iron for the thermal energy storage matrix media. The large quantity of material required is a result of the limited operating temperature range assumed 400°F to 650°F. The 400°F minimum temperature is based on the minimum storage temperature which will still permit delivery of stored energy at a useful temperature for supplying demands, summarized as

1. Combustion air preheating - 600°F.
2. Kiln preheating - 300°F to over 600°F at end of preheating cycle.
3. Dryer - 300°F

The 650°F is a typical operating temperature limit for organic working fluids, such as Therminol 66 (chemically modified terphenyl), although somewhat higher operating temperatures are used in exceptional cases, such as in the Canadian organically moderated reactor (750°F). In the Canadian reactor, high molecular weight/high viscosity fractions, caused by additional polymerization at high operating temperature are continuously removed, with make-up added.

TABLE 3.2-17 COST OF TES UNIT

SENSIBLE HEAT STORAGE IN NaK POOL/IRON CHECKERWORKKEY FEATURES

- OPERATING TEMPERATURE RANGE ASSUMED 400°F TO 1100 °F
- BTU'S RECOVERED DURING FIRING - 156.5 MILLION (38% OF AVAILABLE WASTE HEAT)*
- WEIGHT OF NaK-78 AND IRON REQUIRED - 1181 TONS
(26 TONS NaK-78, 1155 TONS IRON)
- VOLUME OF TES ENCLOSURE - 12,500 FT³
(E.G., VERT. CYL. TANK, 26' HIGH X 12 1/2' RAD.)

COST ESTIMATE

• NaK-78 - 52,000 POUNDS @ \$1.60/POUND	\$ 83,000
• IRON - 1155 TONS @ \$300/TON	346,500
• TANK - 94,000 GALLON CRES	543,000
• SUMP FOR 52,000 POUNDS OF NaK-78	(NOT INCLUDED)
• PUMPS AND MOTORS, HEADERS, INSTALLED VALVES AND PIPING, PURIFICATION, ACCESSORIES	20,000
• EARTHWORK, FOUNDATION AND SUPPORT BED (490 FT ²)	12,500
	<hr/>
	\$1,005,000

UNIT COST

$$\frac{\$1,005,000}{156.5 \text{ MM}} \rightarrow \$6422/\text{MILLION BTU'S CAPACITY}$$

*Table 3.2-8A.

ENERGY CONSERVATION SYSTEM EMPLOYING
THERMOSYPHON PRINCIPLE FOR HEAT TRANSFER/
STORAGE OF THERMAL ENERGY IN SOLID MEDIA

(SENSIBLE HEAT STORAGE)

TO USER: *

- KILN PREHEAT
- COMBUSTION AIR PREHEAT
- BRICK DRYING

LIQUID LOOP: DOWTHERM

FIGURE 3.2-24

TES:

- MATRIX OF ROCKS OR IRON, PEBBLE BED OR CHECKERWORK
- CARBON STEEL TANK, MEDIUM PRESSURE, INSULATED, AND SEALED

TABLE 3.2-18 COST OF TES DEVICE

SENSIBLE HEAT STORAGE IN IRON, DOWTHERM POOL

KEY FEATURES

- OPERATING TEMPERATURE RANGE ASSUMED - 400°F TO 650°F
- BTU'S RECOVERED DURING FIRING - 217 MILLION (52.7% OF AVAILABLE WASTE HEAT)*
- WEIGHT OF IRON AND DOWTHERM - 4822 TONS (4808 TONS IRON, 14 TONS DOWTHERM)
- VOLUME OF TES ENCLOSURE - 51,000 FT³ (E.G., SPHERE 46' DIAMETER)

COST ESTIMATE

● DOWTHERM - 28,000 POUNDS @ \$6.50/POUND	\$ 182,000
● IRON - 4808 TONS @ \$300/TON	1,442,000
● STEEL PRESSURE VESSEL - 382,500 GALLONS	587,000
● PUMPS AND MOTORS, HEADERS, INSTALLED VALVES AND PIPING, ACCESSORIES	10,000
● EARTHWORK, FOUNDATIONS	<u>115,000</u>
	\$2,236,000

UNIT COST

$$\frac{2,236,000}{217 \text{ MM}} \longrightarrow \$10,304/\text{MILLION BTU'S CAPACITY}$$

*Table 3.2-8A.

Ideally, a working fluid will have a normal boiling temperature slightly below ambient, (or, at most, . minimum operating temperature - so leakage will be out of the vessel, rather than having non-condensibles leaking in); high latent heat of vaporization, and low vapor pressure at maximum operating temperature (so the pressure vessel need not contain high pressure and high maximum operating temperature). The Dowtherm's - A or G* were considered for reference, although they do not fully meet criteria given above.

3.2.6 TRADE-OFFS AND IDENTIFICATION OF PREFERRED SYSTEM(S)

Criteria for selection of preferred system(s), stated earlier in Section 3.2.5, include the following categories:

1. Cost: initial and operating/maintenance.
2. Thermal performance: high energy recovery/small temperature degradation.
3. Development requirements.
4. Safety.
5. Commercialization considerations.

Table 3.2-19 summarizes data for comparison of alternative TES concepts. Commercialization considerations are not included in the table, but are discussed below.

Even considering potential for substantial cost reduction by using scrap iron for the thermal energy storage matrix, the concepts using liquid metal or organic working fluid are not competitive because of:

1. High installed cost.
2. High operating and maintenance cost.
3. High hazard.
4. Projected low acceptance by user industry.

These comments, excepting 3 above, also apply to the concept using molten salt and water dilution, in spite of reduction in installed cost for the molten salt thermal energy storage unit compared to its liquid metal counterpart.

The brick checkerwork has the greatest appeal to the brick and refractories industry, since it uses a familiar and - for some plants - immediately available packing media, and may result in an expanded/new product line - checkerwork brick - for the industry. Cost is comparable to cost for the lowest cost alternative - the rock pebble bed - and development requirements are low. Unfortunately, recovery is lower for brick checkerwork than for packing media having much higher surface area per unit volume (iron or

* G is not a constant temperature boiler at constant pressure

TABLE 3.2-19 SCREENING COMPARISON OF ALTERNATIVE TES CONCEPTS

CONCEPT	OPER. TEMP. RANGE (ASSUMED)	CAPACITY OF TES UNIT (MILLION BTU'S)	TES UNIT VOLUME	REFERENCE DIMENSIONS	COST OF TES UNIT INSTALLED	COST PER MILLION BTU'S	SAFETY	DEVELOPMENT REQUIREMENTS	OPERATING & MAINTENANCE EXPENSE	COMMENTS
1A. BRICK CHECKERWORK	400°F-900°F	171	27,000 FT ³	40' X 30' X 25' H	\$81,500	\$477/MM	SAFE	LOW/ INTERMEDIATE	LOW	IN PRACTICE OTHER INDUSTRIES; REJECT BRICK CHEAPER
1B. IRON PEBBLE BED	400°F-900°F	171	15,000 FT ³	30' X 30' X 16½' H	\$630,000	\$3684/MM	SAFE	LOW	LOW	HIGH RECOVERY, PROVEN AT HIGH TEMPERATURE; SCRAP IRON CHEAPER, IF OK
1C. ROCK PEBBLE BED	400°F-900°F	171	26,000 FT ³	50' X 50' X 10' H	\$68,000	\$397/MM	SAFE	INTERMEDIATE	LOW	HIGH H ₂ GIVES HIGH ENERGY AND TEMPERATURE RECOVERY
2. N ₂ OH DRUMS	550°F-800°F	162	25,000 FT ³	22' RAD. X 17' H	\$177,000	\$1092/MM	EXOTHERM & CORROSION FROM WATER	INTERMEDIATE	HIGH	STAINLESS DRUM WOULD INCREASE COST GREATLY; POTENTIAL RECOVERY HIGH
3A. IRON CHECKERWORK IN N ₂ K-78 BATH	600°F-1100°F	157	11,000 FT ³	12' RAD. X 25' H	\$1,200,000	\$7668/MM	HAZARD	LOW	HIGH	HIGH COST AND HAZARD; SCRAP IRON CHEAPER IF OK
3B. IRON CHECKERWORK IN N ₂ K-78 POOL	600°F-1100°F	157	12,500 FT ³	12½' RAD. X 26' H	\$1,005,000	\$6422/MM	HAZARD	INTERMEDIATE	HIGH	HIGH COST AND HAZARD; SCRAP IRON CHEAPER IF OK
4. IRON CHECKERWORK IN DOWNTHERM POOL	400°F-650°F	217	31,000 FT ³	46' DIA. SPHERE	\$2,236,000	\$10,304/MM	HAZARD	HIGH	HIGH	HIGH COST AND HAZARD; SCRAP IRON CHEAPER IF OK

rock pebble bed), or a system of individually connected modules such as the concept for using sodium hydroxide media.

The iron pebble bed has been proven at high temperature (See Figure 3.2-8a, for example), has no favorable characteristics, but higher installed cost. An early demonstration would be facilitated by this choice.

The rock pebble bed has potentially the lowest cost and performance as nearly good as the best (iron pebble bed). Development requirements for the rock pebble bed are discussed in Section 3.2.8. The rock pebble bed is receiving new attention for application at low temperature in solar heating and cooling systems. Application at intermediate temperature (500°F) as a matrix media (granite rock in hydrocarbon oil) for solar thermal power system application is being studied for the ERDA central receiver solar thermal program. Research and development remains to be done for high temperature application of rock pebble beds.

The sodium hydroxide system has potential low cost depending on resolution of media cost uncertainty, but only if cheap, low carbon steel containers can be used. An 800°F limit was assumed for use of low carbon steel drums as containers; above this temperature, it was assumed that more expensive (X10) stainless steel drums would be required. Regardless, use of sodium hydroxide is limited to about 900°F (reference 21 and others). Compared to systems having higher operating temperature limits and wider operating temperature ranges, sodium hydroxide storage systems are increasingly less attractive as the temperature of the waste heat source increases because:

1. Temperature of stored energy is increasingly degraded.
2. Relative amount of sodium hydroxide media required increases.

Application of the stated selection criteria results in the following preference order for the candidate concepts:

CONCEPT	MAJOR IMPLEMENTATION CONSIDERATION
1. Rock Pebble Bed	High thermal performance and lowest potential cost.
2. Iron Pebble Bed	High thermal performance and low development.
3. Brick Checkerwork	User Industry preference.
4. Sodium Hydroxide	Waste heat recovery below 800-900°F.

The figure for thermal energy storage unit cost per million BTU's of capacity, fully charged to fully discharged between specific operating temperature limits is useful for screening of alternative concepts. However, as stated earlier (Table 3.2-8), the unit cost for thermal energy storage provisions to recover a given amount of energy in an actual operation is overstated by this figure, since inputs and outputs can occur simultaneously, decreasing the physical size and capacity requirements for "turning-around" a given amount of energy. Further, the frequency of "turn-around" is not considered by this figure but is important in assessing return on investment. Figure 3.2-25 shows an artist's illustration of a future brick kiln complex designed for energy conservation via integration of any one of the several thermal energy storage concepts. Three thermal energy storage compartments service six kilns in operation, assuming one kiln is fired and started on its cycle each day.

After identification of the rock pebble bed as the reference TES system for near term development and brick kiln application, more detailed evaluations were performed to determine assessments of:

- a) Rock bed geometry.
- b) Development requirements for rock bed TES units.

These are discussed individually in the next two subsections.

3.2.7 ROCK PEBBLE BED DYNAMICS

The packing media property which gives the pebble bed characteristically different behavior from, say, brick checkerwork is the high surface area to volume ratio of the pebble bed media particles. In many cases, it can be assumed that temperature of the media particles at any local point in the bed is equal to temperature of the fluid, including the proposed brick kiln application involving low velocity flue gas or air flow through the bed. Temperature gradients within individual particles are not significant as long as the Biot Modulus is small (below .1, according to reference 27).

During charging, as the heated gas enters the cold bed on one end, the temperature of the bed experiences a sharp rise in temperature at that end. This sharp temperature gradient moves from one end of the bed to the other end of the bed as a moving front, as the charging period continues. Essentially all the energy in the influent stream above initial bed temperature, is recovered. Similar, but opposite behavior occurs during discharging. The recovered energy is supplied with little degradation of temperature, compared to temperature of the charging gas.

The TRANSYS Program (reference 28) available at General Electric Advanced Energy Programs, contains a Rock Bed Thermal Storage component subroutine. This subroutine computes bed temperature as a function of axial station and time, in response to any specified flue gas time-temperature-flow input profile, and any specific initial bed temperature profile. Axial conduction effects, which become increasingly greater with long cycle times, are considered by TRANSYS. An example case (Table 3.2-20) was run on TRANSYS to illustrate the behavior of a rock pebble bed throughout a charging discharging cycle. The bed cross-section area specified for the example is large, to exaggerate the effects of axial conduction. Figure 3.2-26 shows the temperature vs. axial station at various times after start of charge (left hand side) and start of discharge (right hand side). Initial bed temperature is 400°F, and flow is right-to-left for both charge and discharge profiles as drawn. After the initial cycle, the program ran successive cycles of charge/discharge, using the final temperature profile of the preceding cycle as the new initial bed temperature profile. Results

CONCEPT FOR TES INTEGRATED INTO
INTO MULTI-KILN COMPLEX

FIGURE 3.2-25 .

TABLE 3.2-20 PEBBLE BED DYNAMICS

● TRANSYS PROGRAM, PEBBLE BED SUBROUTINE

- COMPUTES BED TEMPERATURE AS A FUNCTION OF AXIAL STATION AND TIME
- AXIAL CONDUCTION EFFECTS CONSIDERED
- ACCOMMODATES TIME-VARYING INPUTS FOR GAS FLOW RATE, DIRECTION AND TEMPERATURE
- ACCOMMODATES REVERSAL OF FLOW DURING RUN

● EXAMPLE CASE PLOTTED

- 400°F INITIAL BED TEMPERATURE
- 10' BED LENGTH; 2130 FT² BED CROSS SECTIONAL AREA
- REFERENCE FLUE GAS TEMPERATURE AND FLOW RATE PROFILE FOR CHARGING PERIOD (T = 7 HOURS TO T = 52 HOURS)
- FLOW REVERSED AT END OF CHARGING PERIOD
- CONSTANT 75°F TEMPERATURE AND 200,000 SCFH FLOW RATE THROUGHOUT 30 HOUR DISCHARGE PERIOD
- ROCK BED PARAMETERS
 - $h_v = 400 \text{ BTU/FT}^3 \cdot \text{HR} \cdot ^\circ\text{F}$
 - $\epsilon = 85 \text{ PCF (APPARENT)}$
 - $C_p = .21 \text{ BTU/LB} \cdot ^\circ\text{F}$
- RUNS MADE WITH AND WITHOUT AXIAL CONDUCTION (FOR AXIAL CONDUCTION $k_{\text{EFF}} = .3 \text{ BTU-FT/FT}^2 \cdot \text{HR-}^\circ\text{F}$)

TEMPERATURE RESPONSE OF ROCK PEBBLE BED TES UNIT TO FLUE GAS INPUT DURING
FIRING CYCLE, THEN COLD (75°F) AIR FLOW OF 200,000 SCFH DURING DISCHARGING CYCLE

0 CYCLE 1 - INITIAL TEMPERATURE OF BED = 400°F

0 FLOW THROUGH 2130 FT² X-SECT. AREA

— WITH AXIAL CONDUCTION

-- W/O AXIAL CONDUCTION

NOTE: THIS IS MINIMUM FLOW RATE
CASE TO EXAGGERATE
AXIAL CONDUCTION EFFECT,
NOT DESIGN CASE

MIRROR IMAGES
(T = 52 CHARGING
IS SAME INSTANT
AS T = 0 DISCHARGING)

for Cycle 7, after near steady-state cycle condition were reached, are shown in Figure 3.2-27. It is apparent that, for these examples:

1. High energy recovery with little temperature degradation is realized.
2. Axial conduction is not a major problem.
3. The bed defined for the example problem is oversized for the specified conditions; the center section of the bed contributes little to the performance.

The pressure drop across a pebble bed storage unit can be large enough to require fan horsepower which is a significant fraction of the energy recovered. Figure 3.2-28, based on data for randomly packed beds of spheres (Figure 3.2-29 and reference 32), shows that the pressure drop for the broadest range of unit mass flows which might be considered and the range of flue gas temperatures, is between .002 and .050 inches of water per foot of bed depth. This indicates that reasonable pressure drops and fan horsepower requirements can be achieved in pebble bed thermal energy storage units for brick kiln applications.

3.2.8 DEVELOPMENT REQUIREMENTS FOR ROCK PEBBLE BED THERMAL ENERGY STORAGE UNIT

The majority of development requirements for the rock pebble bed are design related and are associated with configuration optimization for the kiln application. The basic designs and required components are state-of-the-art and could be implemented today. This section discusses these development requirements for the rock pebble bed concept.

Key considerations for rock pebble bed design are outlined in Table 3.2-21. Premature breakthrough as a result of channeling is a common problem in packed beds, especially beds with non-uniform packing media (scrap iron, for example). In low pressure drop beds, plenum and baffle design is critical for flow balancing, as is inlet ducting and manifolding. Design of the grid or porous septum supporting the bed must be carefully done. Materials selection is important, especially when flue gas condensation can cause corrosion. Thermal cycling can cause attrition and packing of the media, reducing porosity and increasing pressure drop. In addition, a ratcheting action can occur with dumped packings which results in high hoop stresses (or rupture) of the tank containing the bed.

Rock specifications are critical. Uniform size gives maximum porosity. Spherical particles will not orient in plates which obstruct flow, or have excessive channeling or blockage at the edge of the bed near the container wall. Rocks containing hydrated water may fracture or explode on exposure to high temperature, whereas igneous rocks such as granite may not be affected. Friable rocks will spall and wear during thermal cycling. Potentially,

TEMPERATURE RESPONSE OF ROCK BED TES UNIT TO FLUE GAS OUTPUT FROM REFERENCE KILN
DURING FIRING CYCLE, THEN COLD (75°F) AIR FLOW OF 200,000 SCFH (CONSTANT DEMAND)

FIGURE 3.2-27

PRESSURE DROP ACROSS PEBBLE BED

AS A FUNCTION OF TEMPERATURE AND MASS FLOW

*BASED ON THE TOTAL CROSS-SECTION OF THE BED

FIGURE 3.2-28

HEAT TRANSFER AND FRICTION FACTOR FOR FLOW THROUGH RANDOMLY PACKED BEDS OF SPHERES

FIGURE 3.2-29

TABLE 3.2-21 KEY CONSIDERATIONS FOR ROCK PEBBLE BED DESIGN

OPTIMIZATION OF BED LENGTH

- LONG ENOUGH TO AVOID BREAKTHROUGH
- SHORT ENOUGH TO AVOID HIGH ΔP /FAN HP
- GAS DENSITY (FUNCTION OF TEMP.), AXIAL CONDUCTION EFFECTS
- OPERATIONAL SIMULATION

OPTIMIZATION OF PEBBLE SIZE AND GRADATION REQUIREMENTS AND SPECIFICATIONS

- SMALL FOR HIGH H_g , LOW TEMPERATURE GRADIENT IN INDIVIDUAL PARTICLES
- LARGE FOR LOW ΔP / LOW FAN HP
- SHAPE AND GRADATION, STABILITY
- COMMERCIAL QUALITY, FOR LOW COST

BED COMPARTMENTATION AND PACKING

- DESIGN TO AVOID CHANNELLING
- CAPABILITY FOR SIMULTANEOUS INPUT AND OUTPUT WITHOUT STREAM MIXING

GAS/AIR FLOW

- HOT GAS FLOW TOP TO BOTTOM; COLD AIR FLOW BOTTOM TO TOP
- PLENUM, VANE AND INLET DUCTING DESIGN
- POROUS SEPTA

STRUCTURE DESIGN

- BED SUPPORT
- ROCK CONFINEMENT
- THERMAL CYCLING
- THERMAL INSULATION
- LOW COST

MAINTENANCE CONSIDERATIONS

- REPAIR
- CLEANING (CONTAMINATION, ATRITION)
- REPACKING OF MEDIA, REPLACEMENT, SEPTA, ETC.

SAFETY, EASE OF OPERATION, INSTRUMENTATION AND CONTROLS

- ROCK BED IS LOW HAZARD
- ROCK BED OPERATION IS BASICALLY SIMPLE
 - ◆ MODE SELECTION
 - ◆ ROUTING AND RE-ROUTING OF GAS AND AIR STREAMS
 - ◆ MODULATION OF TEMPERED AIR OUTPUTS (AUTOMATIC)
 - ◆ GAS AND AIR TEMPERATURES, IN-BED TEMPERATURES MONITORED

development will identify commercial specifications, and particular rock types among those meeting the commercial specification, applicable to rocks for thermal energy storage. Table 3.2-22 gives size and grading requirements for coarse aggregate used in public works projects in the Commonwealth of Pennsylvania.

Table 3.2-23 summarizes technology development requirements for the high temperature rock pebble bed. Additional simulation results are needed to better resolve brickworks operation and energy savings with integration of various thermal energy storage sizes, schemes, and operating modes. Thermal energy storage unit operating modes must be investigated in more detail, and control requirements and schemes must be elaborated.

Engineering development test requirements in support of rock pebble bed design are outlined in Table 3.2-24. Cold flow tests will provide pressure drop and flow pattern data. Data for various media specifications and packing will also be obtained. Heat transfer and additional pressure drop data will be obtained in hot flow tests. Media test and evaluation will support selection and specification of media, as well as providing data needed for design. Cyclic hot and cold tests will evaluate thermal cycling effects such as media attrition, bed packing, and thermal ratcheting effects. Cyclic tests will also serve to validate the dynamic models and parameters used for performance predictions and operational simulations.

TABLE 3.2-22.

**SIZE AND GRADING REQUIREMENTS FOR COARSE AGGREGATES
(BASED ON LABORATORY SIEVE TESTS, SQUARE OPENINGS)**

PENNA. NUMBER	TOTAL PERCENT PASSING													
	4"	3 1/2"	2 3/4"	2"	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#100	#200
4	100	90-100	35-70		0-15		0-5							
3A			100	90-100	35-70	0-15		0-5						0
2B					100	90-100		25-60		0-10	0-5			
2A				100			52-100		36-70	24-50	16-38*	10-30		0-10
**														
2						100	90-100		20-55	0-10	0-5			
1B								100	75-100	10-30	0-10			
1									100	75-100			10-30	
1NS						100		90-100		0-75				
2NS					100	90-100		0-15						

*Applies only for bituminous mixtures.

**Refer to Section 677 for No. 2RC aggregate.

Note A: A combination of No. 1NS and No. 2NS may be substituted for No. 2B provided that not more than 50 percent nor less than 30 percent of the combination is No. 1NS size.

703.3(c)

Aggregates

703.3(c)

TABLE 3.2-23 TECHNOLOGY DEVELOPMENT REQUIREMENTS

- Further development and exercise of brickworks energy management simulation program
 - Other (than reference) inputs
 - Other demands, more detail
 - Incorporate more detailed TES model
 - More diverse operational simulation; multi-input, multi-output
- Media development and test
- Packed bed development and test
- TES construction materials stability, compatibility, protection
- Elaboration of control logic and points
- Trade-off automation/mechanization/manual control

● Cold Flow Tests

- Flow uniformity as a function of
 - A. Velocity or ΔP
 - B. Media characteristics
 - C. Compartmentation, bed length
 - D. Inlet and outlet configurations, support septum
- Pressure drop as a function of A-D.

● Hot Flow Tests

- Heat transfer as a function of bed and gas temperatures, and A and B above.
- Pressure drop as a function of bed and gas temperatures, and A and B above.

● Media Test and Evaluation

- Apparent density, density, gradation, shape
- Specific heat vs. temperature
- Apparent conductivity, conductivity, surface area
- Petrographic classification, stability, attrition, packing
- Effects of high temperature and heating/cooling rates

● Cyclic Hot and Cold Flow Tests

- Thermal cycling effects on bed
- Validate analytical model and predictions

3.3 EXAMPLE OF INTERMEDIATE TERM (5-10 YEARS) TES CONCEPT

During the study several TES concepts were identified which were not considered to be applicable for near term demonstration, but which show promise for the future. The following describes a TES conceptual approach that is felt to be on the fringe of technical reality, but requires some R&D to specify performance, materials and geometries. It is presented here to show the flexibility available with a fully responsive TES design in an industrial setting, such as is postulated for future periodic kilns complexes.

3.3.1 SYSTEM DESCRIPTION

The TES system is integrated to meet the thermal functional flow diagram shown in Figure 3.3-1.

FIGURE 3.3-1. THERMAL FUNCTIONAL FLOW

The concept must have the option of supplying heat at the approximate levels shown above when integrated with multiple periodic kilns. The two lower temperature demands have a compatible temperature requirement (300 - 600°F). At the higher end of this range, dilution air may be added to prevent a too rapid ware rise-rate in the dryer where flashing of the entrained moisture destroys the structural integrity of the unfired ware. Further, the dryer heat demand is essentially constant while the kiln preheat is dependent on the periodicity of the firing curve. Thus, a minimum demand is always available (dryer) whenever TES load-shedding due to overcharging occurs.

The high temperature (1000°F) stream is dedicated to pre-heating combustion (or secondary) air during firing. The analysis presented earlier, in Section 3.1, shows that at 1000°F, an energy savings of about 40% is possible over a kiln's firing cycle. These demands suggested (at least) two TES stages, a high and lower temperature stage.

1. High Temperature Store - With a temperature of $\sim 1000^{\circ}\text{F}$ this stage will intercept flue and cooling gas streams at times in the kiln cycle when heat flow into this stage is able to support the 1000°F threshold. The heat exchanger for this stage will drop the incoming flue or cooling gas stream temperature, therefore, to approach 1000°F.

The primary function of this stage will be to assure a constant temperature preheat of the combustion (or secondary) air supply to the kiln during the firing period. As a secondary function, this stage will supply excess heat (after satisfying the defined combustion or secondary air requirement) to the lower temperature store.

2. Lower Temperature Store - At a temperature of $\sim 600^{\circ}\text{F}$ (or possibly somewhat lower), this stage of the TES will serve several roles. The working liquid/sensible heat storage media will (1) flux the latent heat media of the high temperature store during start-up, (2) absorb excess heat from the high temperature store during load shedding periods, and (3) supply lower temperature heat in support of drying and/or kiln pre-heating functions. Of necessity, this stage's media must span the working range of the entire store. Ideally, this media would be a liquid from the lowest temperature to the highest level reached in the high temperature store. The candidate liquids are discussed later.

3.3.2 TES CONFIGURATION

Based on contacts with CR&D (GE-Corporate Research and Development, Schenectady), several companies familiar with high temperature latent heat media, i.e., Hooker Chemical, Ajax Electric, and several potential suppliers of TES components, component conceptual designs for the two stages of TES input heat exchangers, the TES envelope and output heat exchangers (shown in Figures 3.3-2 and 3.3-3) were defined. Specific design considerations and operating methods are described below for the major components.

- High Temperature Input Heat Exchanger - A corrugated parallel-plate concurrent flow configuration is a logical choice in that it has high surface area of contact between the hot flue (or cooling) gases and the heat absorbing plates while guarding against over-temperature of the metal plates. On either side of any single flue gas passage, the latent heat media (in its liquid state) removes the absorbed heat. The TES media is pumped through alternate passages between plates of the device.

FIGURE 3.3-2
PROPOSED TES CONFIGURATION

CORRUGATED PARALLEL
PLATE HEAT EXCHANGER

ROTARY REGENERATIVE
HEAT EXCHANGER

FIGURE 3.3-3. CONCEPT DETAILS

During start-up or in preparing for shutdown of this stage, the passages will be drained of the TES media safely before solidification (freezing) occurs, and returned to the TES.

- Lower Temperature Input Heat Exchanger - The rotary regenerative-type exchanger includes several honeycomb-type matrix wheels for high recovery. The wheels are mounted on a common shaft. The wheels are semi-submerged in the sensible heat TES/thermal transport working fluid. Gases exiting the first stage at $\sim 1000^{\circ}\text{F}$ are passed through the honeycomb matrix, transferring the contained heat. As the wheels rotate, the heated matrix enters the bath at between $600 - 1000^{\circ}\text{F}$. Following this "quench" the continued rotation brings the cooled portion of the wheel matrix back into contact with the hot gas stream.
- Storage Container - The basic configuration is a two-chambered, concentric cylinders design separated by an insulating section and bounded by a refractory-lined mild steel jacket. Each chamber is sized to accommodate the heat capacity to be identified by the thermal simulation of the multi-kiln plant installation and operation.

3.3.3 START-UP SEQUENCE

Initial condition:

1. High temperature heat exchanger empty.
2. Low temperature heat exchanger media in liquid state, wheelshaft rotating at low speed.
3. Flue gases passing through both stages as firing commences ($\sim 300^{\circ}\text{F}$).

Procedure:

1. Flue gases preheat the evacuated high temperature heat exchanger plates, remaining heat is extracted and input to the operating lower temperature bath until both reaches about 1000°F .
2. Start pumping the lower temperature media into the high temperature TES store, containing the solidified latent heat media, to melt this stage. The high temperature media change of phase will occur when the cake is at $\sim 1000^{\circ}\text{F}$ (specific temperatures to be specified).
3. Start pumping the high temperature media into the preheated high temperature heat exchanger. When stable operation is evident (return flow to bath is monitored), terminate the lower temperature preheat pumping.
4. With the high temperature TES at hydraulic conditions, simultaneous heat extraction can be initiated from the baths.

5. Shutdown (or reduced capacity) sequence: When incoming flue (or cooling) gas temperatures are below the high temperature media change of phase level, the parallel plate passages containing the latent heat media will be drained by ceasing flow from the bath (TES) and opening drain header valves.

3.3.4 CANDIDATE MEDIA

- Lower Temperature TES/Working Fluid - The temperature requirements for this liquid media is to span the operating range of the TES. Criteria for selection are:
 - Materials compatibility.
 - Safety to equipment/personnel from failure, including reactions in air (toxicity, flammability, pressure, etc.)
 - Stability in operational service, including contact with combustion gas.
 - Physical properties and characteristics.
 - Cost (per BTU between operating temperature limits, especially).
- High Temperature TES Media - This selection is critical in that the cyclic change of phase must be reliably repeatable without loss of congruency, etc. Characteristics of basic media candidates can be altered with the addition of stabilizing agents or other compatible elements, for example, tailoring the melting point to a required temperature. This area must be considered further in succeeding development phases.

3.3.5 TES CONTAINER MATERIALS AND INSULATION

Based on high temperature ($\sim 1000^{\circ}\text{F}$) baths now used in industry, the choice of ceramic fiber blankets and mineral board (outside surfaces) with a refractory liner, all enveloped in a mild steel jacket should be adequate for a first generation system.

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SECTION 4

COMMERCIALIZATION STUDY OF THERMAL ENERGY STORAGE EQUIPMENT FOR THE BRICK/CERAMIC INDUSTRY

This section describes the financial and technical characteristics of the brick/ceramic industry to develop a perspective of the possible relationships between the government (ERDA) and industry for affecting acceptance by plant operators of a successfully developed TES capability. A marketing action plan was developed linking involved public and private agencies into an integrated set of activities to bring TES equipment to the marketplace.

NOTE:

This Commercialization Study was performed by Hendryx Engineers, Inc., of Pittsburgh, Pennsylvania, under a subcontract to General Electric. This firm has been providing the vitrified clay products and non-clay refractories industry with technical consulting, equipment design and fabrication, and total plant planning and construction for over 25 years. Their knowledge of industry responses to new ideas, coupled to the very practical nature of business conduct, reflected by these manufacturers, is clearly evident in the paragraphs that follow. The path of TES acceptance by the potential market is presented, therefore, through the guidance of experts operating within this group and communicated in terms of the industry's unique characteristics and requirements.

4.1 SECTION SUMMARY

Industry Characteristics

Large amounts of heat energy are essential to the fabrication of vitrified clay products from widely available, low cost raw materials. Because of the dependence of the brick/ceramic industry on heat energy, it is highly sensitive to the price fluctuations and availability of fuels. Profit margins and survival of individual plants and companies depend upon adequate supplies of heat energy at costs that can be supported by the operation. Companies may defer plans for capital investment to achieve reduction in fuel requirements because of their uncertainty as to whether the fuel on which the new, more efficient system is based, will continue to be available at a predictable cost through the time the investment must be amortized. Competition in the industry is substantial, and the profit margins are not large. The face brick and sewer pipe producers of the brick/ceramic industry are influenced by variations in the housing market, while the refractories producers are affected by the fluctuating requirements of the steel industry.

The brick/ceramic industry's financial and operating policies are generally conservative, and there is greater reluctance to accept change than in more technically advanced industries. Changes are made as the result of economic necessity and must be well supported by a dependable return on the investment.

Return on investment requirements may be somewhat relaxed only where non-adoption would cause the plant to close.

Action on the implementation of new processes or equipment to meet operating needs is usually initiated by experienced production or engineering personnel, and is presented to the company's owners, or board of directors for decisions on appropriation requests.

Individual companies do not necessarily have a good understanding of the relation of government agencies involved in energy to the brick/ceramic industry. Agency activities are felt through the actions of fuel suppliers (i.e., price regulation via FPC, curtailments) and there is a wide variation in the price and availability of fuel to users in different geographical areas. This inconsistency is a slight deterrent to capital investment for the purpose of saving fuel.

The industry's primary sources of information on new equipment or process designs are technical and trade meetings and publications, and through the efforts of design and consulting engineers or vendors. When a design becomes widely known and the possibility of protecting a competitive advantage no longer exists, the production staffs of companies interested in the design meet to exchange relevant information. Manufacturers usually receive market information directly from their customers, and communications on energy matters are generally given by the energy supplier. Industry association energy committees provide reports to members on their monitoring of government activities in energy-related matters.

Equipment Process Engineering Implementation

Brick/ceramic industry management is concerned about the escalating cost and increasing uncertainty of the supply of fuels. Engineers and production managers are receptive to energy conservation possibilities that can be demonstrated to be dependable and have evidence of sufficient return to amortize the investment. Examples of successful market entry of new equipment and technology include the following:

1. Fork Lift Truck

A fork lift truck was introduced into the brick/ceramic industry at the end of World War II. Feasibility of the use of the fork lift truck was demonstrated in one or two refractories plants, and labor cost savings were verified. In less than five years, the new piece of equipment became the standard in refractory tunnel kiln plants, and full use of the fork lift truck in periodic kiln plants followed a few years later.

Adoption of the lift truck in face brick plants was delayed until 1951 when the development of the gripper fork made possible the use of the truck to handle brick in and out of periodic kilns at substantial labor savings. This service became universal by 1960. Use of fork lift trucks to handle finished face brick awaited the development of a standard strapped package in 1958. Universal use for this service providing labor cost savings came by 1966.

2. High Velocity Burner

The high velocity burner became available in 1968 as a tool for use in tunnel kilns to increase production capability and reduce fuel consumption. The first significant volume of sales, and use of this burner was in 1970. This burner is now used in nearly all new kiln designs. It does not yet fully replace older burners on existing kilns, but sales in 1975 by one manufacturer of high velocity burners increased to twenty-five times the 1970 volume.

3. Insulated Periodic Kiln

Prior to 1957 insulating brick had been used in kiln crowns to effect a substantial reduction in fuel consumption. Completely insulated periodic kilns were introduced about 1957, and the development of improved burner systems for this kiln has contributed to additional major fuel requirement reductions, a shorter firing time, and greater use of the insulated kiln itself.

4. Automatic Brick Handling Equipment

Automatic brick handling equipment was installed in the first plant in 1964 to set brick on tunnel kiln cars. By 1967, six machines were in operation as a result of labor problems which were forcing plants to automate. In 1969, the first automatic unloader from tunnel kiln cars was installed.

Automatic setting is now nearly universal in all major brick plants. The use of automatic unloading is growing as peripheral improvements in drying and firing, which are necessary for the successful operation of automatic unloading, are developed and put into use.

Each of these examples of market entry of new equipment into the brick/ceramic industry was heavily influenced by improvements in processes or equipment which made possible the successful implementation of the basic new equipment.

Industry Perspective of ERDA on Energy Conservation

The industry will expect ERDA to oversee follow-through of R&D and a sponsorship of a pilot operation to demonstrate the feasibility of an energy conservation system involving TES. These efforts should be supplemented through actions by ERDA and other federal agencies to develop policies for creation and implementation of incentives. One such scheme would assure allotments of fuel to companies which utilize TES conservation systems and provide tax incentives for the commitment of capital to TES.

ERDA can communicate facts and advantages of TES to industry through industry supported institutions, publication of technical papers, advertisements, use of engineering consultants and vendors, direct mailings, and through government publications.

Recommendations on Marketing Actions

The successful commercialization of thermal energy storage equipment for the brick/ceramic industry will depend primarily upon the following factors:

- a. Demonstration of a practical TES process through R&D, and a pilot plant program.
- b. Effective support by an industrial energy conservation research and development center which is assumed will be designated (possibly within one of the National Laboratories), to lead in development, pilot operation and communications of technical information to prospective users of TES, and to on-going support in the transition to commercial operations by private enterprise.
- c. Aggressive communication of TES capabilities and the benefits to be derived from its use to the operational and financial management of companies in the brick/ceramic industry with specific attentions to:
 1. Providing evidence that the capital cost of the proposed equipment will be competitive in terms of unit cost of heat energy conserved as compared with other means of conserving heat energy which are already available to the industry, and
 2. Reporting of a convincing demonstration showing the operating cost of a thermal energy storage and heat conservation system does not increase product costs, or reduce profit margins.
- d. Creation of incentives for the use of TES energy conservation systems through the energy policies of government and its agencies with regard to taxation, legislation and regulations covering fuel cost and availability to TES users.

4.2 INDUSTRY CHARACTERISTICS

Three factors combine to influence the operating procedures with respect to energy in the brick/ceramic industry; company-industry organization, production process and facilities, and financing-pricing policies. These three influences form a consistent whole, impinging on each other and integrating individual companies into an industry. Specific to TES acceptance, changes in processes and equipment, management decision paths to changes, industry sensitivities and communications channels complete this description of industry characteristics.

4.2.1 COMPANY-INDUSTRY ORGANIZATION

Most companies in the brick/ceramic industry began as small independent operations. Larger organizations were formed as the stronger companies bought out or merged with other compatible operating units. More recently, particularly in the refractories industry, still larger conglomerate organizations have obtained financial control over the larger companies. Some sewer pipe producers are part of larger companies which also produce centrifugally cast ductile iron pipe. More companies in the face brick manufacturing category remain independent than in any other segment of the industry. Still, some are part of conglomerate organizations which are involved with other construction materials.

4.2.2 PROCESS AND PRODUCTION FACILITIES

A unique element in the brick/ceramic industry is the need for a large amount of heat energy to produce the superior properties of ceramic products needed

by the markets. These properties are the result of an elementary heat process being applied to common, low-priced raw materials, with the exception of certain high quality refractories. The unique property which face brick and sewer pipe have in common is a vitrified body. Most face brick and sewer pipe are produced from clays or shales, or combinations of the two. These materials generally consist of alumina, silica, and a variety of other smaller quantities of inclusions or impurities. When heated to a high enough temperature, they can combine to create a glassy matrix. When cooled, this substance has the properties of high strength, low porosity, low permeability, permanent color and texture, resistance to attack by acids and chemicals, and resistance to attack from freezing and thawing. (1). Refractories by definition are materials designed to contain heat. They are usually required to withstand chemical attack and resist abrasion from molten metal and slags. Firing the refractory materials to elevated temperatures is a process by which heat resistant materials are bonded into a product which can withstand chemical attack, resist abrasion, and contain heat (Naturally occurring materials with these properties within the earth's crust are inadequate and are in very limited supply).

Because the brick/ceramic industry involves production of heavy tonnage of relatively low-priced products, the cost of transportation is a major factor. Many producing units were originally located close to raw material sources, but more recently, particularly in the refractory industries, this trend has reversed. New plants have been located close to the market for that particular product. As a result, a greater number of small-sized production units have been built as compared to the few large, centralized new production units.

4.2.3 FINANCIAL POLICIES

Because many of the companies in the industry began on a relatively small scale, the financial operating policies developed by management have been guided by relatively simple financial principles. Most have been free to follow their individual ideas so there is diversity in financial control methods. Where larger conglomerate organizations have taken control, more sophisticated accounting procedures and financial planning have been put into effect.

Smaller companies often have less liquid assets than their larger counterparts, and so tend to maintain a general policy of make-do, wear-it-out, and use-it-up. In the larger companies, with more control of financial reserves, and competition for the limited quantity of available capital funds, a reasonably fast return on investment is necessary if the ceramic plant is to commit capital to an investment.

Two quite different approaches are used in the brick/ceramic industry for measuring project rate of return; the financial statement method and the discounted cash-flow method. Under the financial statement method, capital employed in a project and the related income, are determined by methods used in accounting for assets and income. That is, the initial amount of capital invested in the project is established by the amount of capitalized expenditure and project income is taken after deducting depreciation and all other applicable charges. Rate of return may be computed on the amount of the original investment or on average investment over the life of the project. The different investment bases can result in materially different rates of return for the same project. An even greater simplification of the financial statement method is the simple pay-back calculation which divides the net investment by the incremental income to be received per year to secure a pay-back in years.

The discounted cash flow method does not allocate project costs or income to interim periods through the use of capitalization and depreciation procedures. Instead, rate of return is developed from cash flows identified with the project. The time value of money is recognized by discounting cash flows to the same point in time. The rate of return is computed on the amount of investment actually unrecovered from time to time. The process is analogous to the amortization of a mortgage debt where periodic payments are applied first to payment of interest on the amount of unpaid principal, with the remainder applied to the reduction of principal. In the project evaluation, the rate of interest is the unknown factor. It may be defined as a rate at which all income from the project will be absorbed by interest earnings and recovery of capital over the project's life (2). The discounted cash flow method has been developed with a number of variations. Basically, it accounts for the present value of income to be received in future years rather than the return at the present time, at its full dollar value in the future. Calculations are made using interest tables that give the present value of money at various rates for "N" years into the future. Figure 4-1 shows return on investment calculated using simple payback, by the financial statement method and by a simplified cash flow method. These methods can be used to arrive at a percent rate of return. The relationship between the percentage rate of return for various projects can then be compared.

The general pattern is such that financing for major equipment or process changes comes when new equipment or processes will reduce costs or improve product quality, when the changes are forced by rising costs for labor, material, or supplies, or when there is actual or threatened curtailment of supplies necessary for the continuation of business. The brick/ceramic industry has been quite competitive, and with a few exceptions, the profit margin is not generally high. The small number of companies in this industry (within a market area) keep price competition keen. Foreign competition has not been a major factor except in specific situations such as when a minor amount of higher priced refractories have been imported when the relative currency valuation between the United States and the producing country has been favorable. Some building bricks have been imported from Mexico at cut-rate prices, but their quality is not dependable.

Prices of face brick and sewer pipe are affected by the competition of non-ceramic materials. The face brick industry has competition from other structural materials, including wood, steel, aluminum, plastic, and glass. The ceramic sewer pipe industry is faced with competition from plastic pipe in smaller sizes and from concrete pipe in larger sizes. Competition is intensified in the refractory industry by the research efforts of the major steel companies in comparing technical properties of refractory products, and also company furnace lining performance records in terms of the number of heats obtained from each lining. Since steel companies evaluate supplies in terms of cost of material per ton of steel produced, this technical service analysis exerts pressure on prices as well.

The necessity of a return on investment in relation to energy conservation programs is not peculiar to the brick/ceramic industry. Bruce Chalmers and Gordon McKay, Professors of Metallurgy at Harvard, write, in a recent issue of Harvard Magazine (3), about the need for a Department of Energy to predict our energy needs and to contract with industry to meet them. Touching on this in connection with the development of substitute energy sources, the article cites:

SIMPLE PAY-BACK			SIMPLIFIED METHOD FOR CALCULATING DISCOUNTED CASH FLOW RETURN ON INVESTMENT		
PAY-BACK PERIOD (YEARS)	=	$\frac{\text{NET INVESTMENT}}{\text{INCREMENTAL INCOME/YR}}$	GROSS INVESTMENT		\$10,000
PAY-BACK PERIOD = $\frac{\$10,000}{4,000}$	=	2.5 YRS.	ESTIMATED LIFE:	10 YEARS	
FINANCIAL STATEMENT METHOD			ANNUAL PAY-BACK BEFORE DEPRECIATION AND INCOME TAXES		\$4,000
AMOUNT INVESTED		\$10,000	LESS: STRAIGHT-LINE DEPRECIATION OF NET INVESTMENT		<u>\$1,000</u>
ANNUAL INCOME AFTER TAXES, PLUS DEPRECIATION		4,000	INCREASE IN TAXABLE INCOME		<u>3,000</u>
ANNUAL DEPRECIATION CHARGE $\frac{\$10,000}{10 \text{ YRS.}}$	=	1,000	INCREASE IN INCOME TAX AT 48% TAX RATE		1,440
ANNUAL NET INCOME		3,000	NEW CASH FLOW AFTER TAXES		<u>2,560</u>
RETURN ON INITIAL INVESTMENT	$\frac{\$3,000}{10,000}$	= 30%	PAYBACK YEARS		
RETURN ON AVERAGE INVESTMENT OF 5,000	$\frac{\$3,000}{5,000}$	= 60%	NET INVESTMENT		10,000
					<u>=3.90 YRS</u>
			NET CASH FLOW AFTER TAXES		\$2,560
			RATE OF RETURN: Refer to TABLE 4-1 and locate the pay-back years (3.90) on the row corresponding to the estimated life (10). The column where the figure closest to 3.90 appears shows the rate of return. In this case, it would be estimated at 25.6% as follows: In the 26% column, the figure is 3.86; in the 25% column, it is 3.963. The rate of return for a period of 10 years lies between these two percentages, and it is therefore approximately 25.6%.		

FIGURE 4-1. TYPES OF RETURN ON INVESTMENT CALCULATIONS

TABLE 4-1.

PRESENT VALUE OF \$1/12 RECEIVED MONTHLY FOR N YEARS

Years (N)	1%	2%	4%	6%	8%	10%	12%	14%	15%	16%	18%	20%	22%	24%	25%	26%	28%	30%	35%	40%	45%	50%
1	0.995	0.989	0.979	0.968	0.959	0.950	0.941	0.932	0.928	0.924	0.915	0.907	0.899	0.892	0.888	0.884	0.877	0.870	0.853	0.837	0.822	0.808
2	1.979	1.959	1.928	1.895	1.868	1.844	1.821	1.799	1.775	1.750	1.691	1.663	1.637	1.611	1.598	1.586	1.562	1.539	1.485	1.435	1.390	1.347
3	2.954	2.910	2.828	2.744	2.670	2.599	2.531	2.467	2.436	2.406	2.349	2.293	2.241	2.191	2.167	2.142	2.098	2.054	1.953	1.863	1.781	1.704
4	3.920	3.843	3.698	3.559	3.433	3.319	3.201	3.086	3.046	2.998	2.905	2.818	2.736	2.654	2.621	2.585	2.516	2.450	2.300	2.168	2.050	1.946
5	4.876	4.757	4.533	4.327	4.137	3.962	3.799	3.648	3.577	3.509	3.377	3.256	3.142	3.036	2.985	2.936	2.842	2.755	2.557	2.396	2.238	2.106
6	5.822	5.653	5.338	5.051	4.790	4.551	4.333	4.132	4.036	3.948	3.778	3.620	3.475	3.340	3.276	3.214	3.098	2.989	2.747	2.541	2.365	2.212
7	6.759	6.531	6.111	5.734	5.395	5.088	4.810	4.557	4.439	4.327	4.117	3.924	3.748	3.585	3.509	3.435	3.297	3.169	2.888	2.653	2.459	2.283
8	7.687	7.392	6.855	6.379	5.954	5.575	5.235	4.929	4.768	4.654	4.404	4.177	3.971	3.793	3.695	3.611	3.453	3.308	2.992	2.732	2.514	2.330
9	8.605	8.237	7.571	6.987	6.473	6.018	5.615	5.256	5.091	4.935	4.647	4.388	4.154	3.942	3.844	3.750	3.575	3.414	3.070	2.789	2.556	2.362
10	9.515	9.065	8.259	7.560	6.953	6.421	5.955	5.543	5.355	5.178	4.854	4.564	4.305	4.071	3.963	3.860	3.670	3.497	3.127	2.828	2.565	2.369
11	10.415	9.876	8.920	8.101	7.397	6.788	6.256	5.794	5.584	5.388	5.029	4.711	4.428	4.175	4.050	3.948	3.744	3.560	3.169	2.858	2.605	2.397
12	11.307	10.672	9.556	8.612	7.809	7.121	6.538	6.015	5.784	5.568	5.177	4.833	4.529	4.259	4.135	4.018	3.802	3.608	3.201	2.879	2.619	2.406
13	12.189	11.453	10.167	9.094	8.190	7.423	6.770	6.208	5.957	5.724	5.302	4.935	4.611	4.326	4.196	4.073	3.847	3.646	3.224	2.894	2.629	2.412
14	13.063	12.217	10.755	9.548	8.542	7.699	7.045	6.378	6.108	5.858	5.409	5.019	4.679	4.380	4.245	4.117	3.883	3.674	3.241	2.904	2.635	2.417
15	13.928	12.967	11.321	9.977	8.869	7.949	7.179	6.527	6.239	5.973	5.499	5.090	4.735	4.424	4.284	4.152	3.911	3.696	3.254	2.912	2.640	2.419
16	14.785	13.702	11.854	10.381	9.171	8.176	7.350	6.658	6.353	6.073	5.576	5.149	4.780	4.460	4.315	4.179	3.932	3.713	3.264	2.917	2.643	2.421
17	15.633	14.422	12.387	10.762	9.451	8.383	7.503	6.772	6.452	6.159	5.640	5.188	4.818	4.488	4.340	4.201	3.949	3.725	3.271	2.921	2.645	2.422
18	16.473	15.129	12.890	11.122	9.712	8.571	7.640	6.873	6.539	6.233	5.695	5.239	4.868	4.511	4.360	4.218	3.962	3.736	3.276	2.924	2.647	2.423
19	17.305	15.822	13.373	11.462	9.951	8.742	7.763	6.961	6.614	6.297	5.742	5.273	4.873	4.500	4.345	4.202	3.943	3.714	3.240	2.926	2.648	2.424
20	18.128	16.501	13.836	11.782	10.173	8.897	7.872	7.038	6.679	6.352	5.781	5.301	4.894	4.515	4.349	4.203	3.941	3.750	3.263	2.927	2.648	2.424
21	18.943	17.167	14.285	12.084	10.379	9.038	7.969	7.108	6.735	6.399	5.815	5.325	4.911	4.537	4.369	4.252	3.987	3.755	3.285	2.928	2.649	2.424
22	19.750	17.819	14.714	12.369	10.579	9.167	8.056	7.165	6.786	6.440	5.843	5.345	4.925	4.547	4.407	4.259	3.992	3.758	3.288	2.929	2.649	2.425
23	20.549	18.459	15.127	12.638	10.746	9.283	8.134	7.218	6.828	6.478	5.867	5.361	4.938	4.574	4.414	4.264	3.996	3.761	3.287	2.929	2.649	2.425
24	21.341	19.087	15.523	12.892	10.909	9.389	8.204	7.263	6.865	6.506	5.887	5.375	4.945	4.581	4.419	4.269	3.999	3.763	3.288	2.930	2.650	2.425
25	22.124	19.702	15.906	13.131	11.061	9.486	8.266	7.304	6.897	6.532	5.904	5.386	4.953	4.588	4.423	4.272	4.001	3.765	3.289	2.930	2.650	2.425
26	22.899	20.305	16.274	13.357	11.201	9.574	8.321	7.339	6.926	6.555	5.919	5.398	4.969	4.590	4.426	4.275	4.003	3.766	3.289	2.930	2.650	2.425
27	23.667	20.896	16.627	13.570	11.331	9.653	8.370	7.370	6.950	6.574	5.931	5.404	4.964	4.593	4.429	4.277	4.004	3.767	3.290	2.930	2.650	2.425
28	24.428	21.476	16.966	13.771	11.451	9.726	8.415	7.397	6.971	6.591	5.942	5.410	4.968	4.596	4.431	4.279	4.005	3.768	3.290	2.930	2.650	2.425
29	25.180	22.044	17.293	13.961	11.562	9.792	8.454	7.421	6.990	6.606	5.951	5.416	4.972	4.598	4.433	4.280	4.006	3.768	3.290	2.930	2.650	2.425
30	25.928	22.601	17.607	14.139	11.665	9.852	8.489	7.441	7.004	6.618	5.958	5.420	4.975	4.600	4.434	4.281	4.007	3.769	3.290	2.930	2.650	2.425
40	32.985	27.805	20.153	15.454	12.354	10.220	8.684	7.550	7.047	6.470	5.932	5.440	4.986	4.606	4.439	4.285	4.009	3.770	3.291	2.931	2.650	2.426
50	39.375	31.711	21.873	16.191	12.676	10.361	8.752	7.586	7.107	6.622	5.999	5.443	4.987	4.607	4.440	4.285	4.009	3.770	3.291	2.931	2.650	2.426

Note: It is assumed that monthly increments earn simple interest until the end of each year and that entire amount is discounted annually.

$$\text{Formula: } \frac{1 - (1 + i)^{-N}}{i(1 + i)^{1/12} - 1}$$

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Figure 4-2b

"Coal is plentiful . . . it can be converted into oil and into a satisfactory substitute for natural gas. Why are we not doing this? The answer is simply that the oil and gas so produced would cost more than the 'natural' fuels we use now; and the same applies to the extraction of oil from shale and from tar sand. Whether these resources should be developed or not is in the long run a question of whether the price, in human and ecological terms, of coal mining is too high to pay, in view of the alternative sources of energy. However, this is not the question that is asked by corporations. The criterion is not whether we need these fuels, but whether it will be profitable to produce them. Customarily, in keeping with the social and political traditions of this country, the only way for a new industry to start, or for an existing one to expand, is to attract investment by the promise of future benefits."

4.2.4 EQUIPMENT-PROCESS CHANGES

As with other private enterprise, brick/ceramic industry management are receptive to new/modified process equipment only where these changes are shown to be profitable. Because of the organizational structure of the industry, it is less inclined than other industries to accept drastic changes without strong evidence of gains.

Changes of equipment that sustain the basic process are more readily accepted than those that alter the complete process. Since thermal energy storage as applied to the firing process in existing ceramic plants would not basically affect the process, it is felt this new capability meets the more favorable criteria for introduction into the industry.

The brick/ceramic industry is often reluctant to accept technical change in line with the industry's generally conservative image, but the need to protect and improve profit margins by reducing costs is so well understood that it is forced to seriously consider any well-documented innovation offering cost savings. Change is then accepted when the proof of the value of the change can be demonstrated.

4.2.5 MANAGEMENT DECISIONS AND RESPONSIBILITIES FOR CHANGE

Since the larger refractory companies are effectively under the control of parent corporations, it is common for these companies to require annual and five year plans, including capital budgets. Within the framework of the annual capital budget, specific requests for capital appropriations are prepared to cover changes in equipment or technology requiring investment. These proposals must be supported by return on investment calculations which are reviewed by the accounting department of the company. Proposals for the adoption of new equipment and technology must have the endorsement of the production management staff and must be supported with technical recommendations by the engineering staff of the company. Companies not having an in-house engineering staff, consider proposals requiring capital investment, made by consulting engineers who may serve the operating management of the company in much the same manner as in-house engineers.

The smaller refractories companies making face brick and sewer pipe usually follow similar procedures with regard to capital investment proposals with varying degrees of sophistication. Larger sewer pipe companies that are a part of parent corporations producing products other than ceramics follow the same general procedure as the larger refractory companies. Small companies controlled by the owner or family may operate on a more informal basis with direct participation of the owners in planning and capital investment decisions. In nearly every case everyone concerned, from the plant production staff, to the board of directors, is aware of the cost impact on the operation of the company, in making any major change in equipment or technology.

Proposals for expansion of plants or construction of major new facilities normally originate at a level in the company where the management involved would be directly concerned with marketing and sales, as well as production. Proposals for the use of new technology or new equipment to improve efficiency, or provide cost savings, frequently originate at the plant production level where managers and engineers are most aware of the processes and their operating costs. This is particularly true in companies where cost accounting systems make this information available to operating managers. Submission of proposals to a company for improvements in technology or an addition of new equipment would normally be taken up first with production management and plant engineers who are held responsible for costs and efficient performance. Proposals calling for very large capital investments may need to be submitted to top management as the magnitude of the proposal may be beyond the level of responsibility accorded to the plant staff.

In larger companies where professional controllers, managers, boards of directors, and other top management personnel may not have plant operating and technical experience, a new project must have a well documented financial analysis, and the approval and recommendations of production management and research and technical staff to merit acceptance. In smaller companies where executives have progressed through the ranks of production management, plant level production and technical staff may be consulted about proposed changes though their responsibility for initiating plans for major changes may be limited. In either case any new equipment or process technology project must secure the support of the experienced production and technical people at whatever level they occupy in the organization. Figure 4-2 indicates management functions and responsibilities for technical change in companies of various sizes. It should be noted that while ultimate decisions rest with the board of directors, chief executive, or owner, they normally will not act without having firm recommendations from their engineering, production and R&D people.

There is an exception to the principles of payback and ROI normally required for approval of projects. New equipment and technology may be used when a slower pay-back is predicted if this is a necessary cost of continuing business. Where non-adoption would cause the plant to shut down, or make substantial curtailments of operations due to lack of necessary supplies, new equipment and processes might be adopted without requiring the normal rate of pay-back even though a reduction of profit margin to close to the break-even point is forecast. Even then the purchase of new equipment with a lower return on investment would only occur if the profit margin was adequate to carry the added fixed costs. Frequently plants do not have the margin to carry additional fixed costs, so it is not uncommon for companies to close plants or cease operations entirely when new requirements call for investments which will not produce an adequate return.

	NEW TECHNOLOGY	PROCESS CHANGE	NEW EQUIPMENT	APPRO- PRIATION REQUEST	APPRO- PRIATION DECISION
<u>LARGE COMPANIES</u>					
Board of Directors	3	3	3	-	1
Ch. Exec.	1	1	1	1	-
Financial	-	-	-	2	-
Production	2	2	2	1 & 2	-
Engineering	2	2	2	1 & 2	-
R&D	2	2	2	-	-
Sales Marketing	3	3	3	-	-
<u>MID-SIZE COMPANIES</u>					
Bd. Dir./Ch. Ex./Owner	1	1	1	-	1
Financial	-	-	-	2	-
Production	2	2	2	1 & 2	-
Eng. or Consultant	2	2	2	1 & 2	-
R&D	2	2	2	-	-
Sales/Marketing	3	3	3	-	-
<u>SMALL COMPANIES</u>					
Bd. Dir./Ch. Ex./Owner	1	1	1	-	1
Production	2	2	2	1	-
Sales	3	3	-	-	-
Eng. Consultant	2	2	2	2	-

KEY: 1. Decides 2. Recommends 3. Alerts Others

FIGURE 4-2. MANAGEMENT FUNCTIONS AND RESPONSIBILITIES
FOR TECHNICAL CHANGE.

4.2.6 SENSITIVITIES OF THE BRICK/CERAMIC INDUSTRY

In addition to market demand changes, the brick/ceramic industry is particularly sensitive to energy matters because of its energy intensive nature. It is therefore particularly concerned over government influences in connection with energy matters.

1. Market Actions

Pressures from customers and competition requires many manufacturers in the industry to carry a heavy inventory to meet customers' demands for rapid delivery. This enables customers to minimize their capital investment in inventories. When the refractories industries are approaching full capacity, customers build up inventories. When refractory use drops, users stop all shipments covered by inventory stocks so that refractories companies operate under a multiplier of the effect of market conditions. This is also true of both the face brick and sewer pipe industries. Both of these industries are heavily dependent on the housing market. As the housing market fluctuates, these industries are subject to abrupt changes in market requirements.

2. Energy Matters

Sensitivity to the energy situation is acute in the brick and ceramic industries, being producers of energy intensive products. Less than

adequate energy supplies means production may be reduced to below the break-even point. Plants in these industries have a substantial fixed investment. A major part of this is in the kilns where energy is used. Because of the wide variations in capital cost for the various sizes and types of plants producing refractories, face brick, or sewer pipe, it is not possible to give a breakdown of the "typical" capital costs of buildings, machinery, or firing equipment. However, in most situations the cost of the kilns and dryers, the major energy consuming items, generally falls in the range of 25-35% of the total capital cost of the plant.

Companies are particularly sensitive to impacts associated with energy, including the cost of changes involving energy conservation, because the cost of energy is a major component of the total cost of manufacturing brick and ceramic products. Changes that would conserve energy but increase the overall cost of the energy component in manufacturing, are resisted because an increased cost of energy cannot be supported while profitability is maintained.

The wide range of prices for fuel and the variation in kiln efficiencies make it difficult to be specific about the percentage of total manufacturing cost represented by fuel energy cost. The cost of fuel energy ranges from approximately \$.60/MM BTU for cheap gas, to as much as \$2.40/MM BTU. L.P. gas is even more costly. Face brick and sewer pipe plants with a mix of kilns may use from 2 MM BTU/ton of ware up to 10 MM BTU/ton. Fuel energy cost then ranges anywhere from \$1.20/ton of ware fired with cheap interstate gas for firing face brick in a modern, efficient, tunnel kiln, to as much as \$20.00/ton to fire sewer pipe with #2 oil in an old style periodic kiln.

From experience, the average amounts of fuel required to fire face brick and sewer pipe in tunnel kilns and periodic kilns would be approximately as follows:

	MILLION BTU/TON OF WARE
Face brick fired in tunnel kiln	2.5 to 3
Face brick fired in periodic kilns	4 to 6
Sewer pipe fired in tunnel kilns	4 to 6
Sewer pipe fired in periodic kilns	8 to 12

Refractories are fired to higher temperatures than face brick and thus must carry substantially higher energy costs somewhat proportionate to the required cure temperature. Sewer pipe carry higher energy costs for firing face brick, as less tonnage of material can be set in the kiln because of the high volume to weight ratio of these products.

Companies are keenly sensitive to the effect of external alterations in the energy supply, including changes in the cost of fuel, types of fuel available and threatened or actual curtailments of the fuel supply. Many companies are becoming increasingly interested in methods allowing for the use of standby fuel, but are uncertain about the increased cost and possible unavailability of the standby fuel under consideration. Because of the uncertainty in these areas, decisions are unavoidably delayed.

3. Government Influences

The energy committees, of The Refractories Institute (TRI) (4), the Brick Institute of America (BIA) (5), and the National Clay Pipe Institute (NCPI) (6), the major industry associations, have mounted a major effort to keep abreast of all energy related activities of government agencies and Congress. Through these industry institutes communications have been recently intensified between the manufacturers members of Congress and the appropriate federal and state agencies. Thus far, the policy of the industries has been to voluntarily and promptly comply with requests from government agencies concerning energy matters in the hope of forestalling mandatory regulations or restrictions on their use of energy. The Refractories Institute is attempting to educate Congress and the appropriate federal agencies in the role refractories play in the production of all iron, steel, and non-ferrous metal products so that federal decision makers understand that allocation of heat energy to the refractories industry is absolutely necessary to maintain production of metals.

The brick/ceramic industry is particularly sensitive to the number of government agencies acting in the energy area, the lack of predictability of the actions of these agencies, and the effect agency actions can have on the ability of the ceramic industries to survive. Because of this uncertainty, the companies feel they are unable to make intelligent plans to secure the necessary heat energy to continue production.

Generally speaking, there is a lack of clear understanding within the brick ceramic industry of the specific roles of ERDA, the FEA, and other governmental bodies whose actions may affect the availability and the cost of fuel energy to the individual companies. Contributing to this uncertainty is the wide variation in the cost of inter-and intra-state gas in various geographic areas, the range of prices for the different grades of fuel oil, and the differences in the amount of gas fuel allocated to one company when compared to another company making the same product in another area. This tends to cause the individual energy user to adopt the shortest range policy possible for securing the necessary fuel energy because it presents the least risk. Long range plans that might provide more economy are then deferred because the cost or availability of the alternate fuel is considered to be too uncertain to support the adoption of a different energy program. The industry's understanding of the roles and linkages assigned to the agencies involved in energy-related issues, having an effect on TES uses in industry are as shown in Table 4-2. The actions of government agencies with regard to the

TABLE 4-2. ENERGY RELATED GOVERNMENT AGENCIES - THEIR ROLES AND LINKAGES

AGENCY	ROLE	LINKAGES
DEPT. OF COMMERCE	<ol style="list-style-type: none"> 1. Develops industrial energy. 2. Monitors industrial energy use. 3. Statistical analysis and projections of industrial growth and energy demand for commerce. 4. Monitors competitive environment among industries to markets served. 5. Sets standards of performance for processes and equipment. 6. Conducts testing of new equipment per standards (5 above). 7. Publishes reports of government sponsored contracts (NTIS). 	<ol style="list-style-type: none"> 1. Reports energy demand data to FEA. 2. Cabinet level influence on other agencies. 3. Close ties with industry trade association.
FEDERAL ENERGY ADMINISTRATION	<ol style="list-style-type: none"> 1. Official policy setting agency on energy matters. 2. Recommends energy pricing strategies, allocates energy resources. 3. Oversees government interactions related to energy. 4. Evaluates domestic energy situation (Council of Environmental Quality) and advises Executive Office. 5. Directs national energy policy programs including goal setting for conservation. 6. Recommends incentives and is likely to be the regulating agency in energy as EPA is for environmental standards. 	<ol style="list-style-type: none"> 1. Can influence directions of technology and research priority. 2. Recommends legislation on energy prices (rate setting) and curtailment priorities. 3. Cooperative program with Dept. of Commerce to monitor industry energy use improvements due to conservation efforts.
ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION	<ol style="list-style-type: none"> 1. Manages and conducts R&D of all energy forms directed towards each of the energy-consuming markets. 2. Provides input and reviews of energy-related programs to other energy agencies and Congress. 3. Recommends priorities for national efforts based on technical and economic assessments of state-of-the-art science and technology positions. 4. Sponsors forums for technical interchange and information dissemination of technical matters involving energy systems. 	<ol style="list-style-type: none"> 1. Interface between industry and government in energy technologies. 2. Advises Congress on attainable energy impacts for given resources and manpower levels. 3. Directs and coordinates interagency energy R&D programs.
NATIONAL LABORATORIES & NASA	<ol style="list-style-type: none"> 1. Support ERDA in developing technologies related to energy systems. 2. Manages technology areas for ERDA. 3. Recommends programs and R&D needs to ERDA. 4. Conducts in-house R&D in specialty areas. 5. Defines and awards programs (initially) in charter areas under ERDA cognizance and/or approval. 	<ol style="list-style-type: none"> 1. Advises ERDA on technology status and recommends emphasis in future work in specialty areas.
FEDERAL POWER COMMISSION	<ol style="list-style-type: none"> 1. Directly responsible for rate setting on energy (domestic) supplies. 2. Enforces legal conflicts between government and utilities. 3. Maintains in-depth technical resources to assess supply-demand-economic situations of energy resources. 4. Implements policies affecting energy supply and prices established by FEA. 	<ol style="list-style-type: none"> 1. Advises FEA on energy supply-demand imbalances and economic impacts of rate changes.

allocation of supply and the cost of energy impinge on the end user through the actions of the utilities. As suppliers to the end use markets, utilities are protected monopolies. They are governed by the FPC and other interstate agencies. Within the state, the Public Utility Commission controls utilities, to some level below the federal groups, particularly where a utility serves more than one state. Competition for available natural gas within a state (unregulated by the FPC) results in much higher prices for intra-state gas than inter-state gas commands. However, interruption of intra-state gas contracts is less likely, so often the higher price is justified by a relatively assured supply to the customer.

Thus far, utilities offer little incentive to conserve gas. Frequently their rate structure even favors waste in that higher volume consumption is complemented by lower prices. A similar situation exists with electric utilities. Reversal of these archaic rate bases is required to effect a strong energy conservation program. Raising fuel prices without changing the rate structure allows the utilities to pass the additional raw energy costs to the consumer who, in turn, boosts his product retail prices accordingly. No one gains in this vicious loop. In fact, curtailments and higher fuel prices as experienced by the vitrified clay products industries have had two severe negative impacts.

1. Forced plant closings and business default.
2. Increased competition for products by pricing clay products out of reach and other materials into the market.

This has been particularly evident in the face brick industry (SIC 3251) where wood and wood-derivative building materials, steel and glass have increased their holds on the construction industry. From an energy point of view, construction financing is first cost-sensitive; thus, less energy efficient methods are chosen for their relatively lower capital costs. However, given the life cycle of the structure, space heating and cooling operating costs would justify brick selection. Structural advantages also accrue with use of brick and cement construction. The utilities (and FPC) can do much to improve this situation and thereby spur energy conservation efforts with financial incentives to their markets. Trade associations in this group include the American Gas Association (AGA), American Petroleum Institute (API), National Coal Association (NCA), and Edison Electric Institute. EPRI (Electric Power Research Institute) is a new combine formed specifically to concentrate on new electric power sources and more efficient generation; its objective to extend our fossil-fuel reserves over a longer period and still satisfy growing demands for electricity.

4.2.7 METHODS OF COMMUNICATION WITHIN THE INDUSTRIES

Communications between companies on new equipment and process designs is primarily through vendors or engineers who are involved in equipment design. When a company develops useful improvements in equipment and processes internally, publicity is avoided if the development provides an opportunity to maintain any competitive advantage. Unless this information is proprietary and protectable by an individual brick/ceramic industry product manufacturer,

vendors make every effort to publicize new equipment and processes. Independent engineering designers try to promote the use of any new design. When a new design or piece of equipment becomes widely known and used, the production people within the industry then exchange information to their mutual advantage.

Communication of market information with the industry, particularly specific changes in the market situation, is directly from the customers to the suppliers. Many companies subscribe to information services and follow economic reports by consulting economists or banks. Information is also secured from such common sources as the Wall Street Journal and from occasional reports on market conditions printed in trade magazines. Some companies subscribe to economic counseling services such as those provided by Lionel D. Edie & Company, Inc. Another service is the Kiplinger Washington letter issued by Kiplinger Washington Editors, Inc., Washington, D.C., 20006. An example of a bank service is Economic Comment issued by the Economics Office of Mellon Bank, Pittsburgh, Pennsylvania (See Appendix B-1). Trade magazines such as Iron Age, Brick & Clay Record, Industrial Furnaces, Industrial Gas, and other similar publications, generally read by managers and engineers in the brick/ceramic industry, often have extensive market forecasts for the industry towards which the trade magazine is directed.

Communications with the industry on energy matters is directly from the fuel energy supplier to the customer or from government agencies, if regulations are being considered or imposed. Industry association committee reports of the TRI, BIA, and NCPI provide members with the information gathered by their monitoring of the activities of Congress and government agencies. An intra-industry communication on the subject of energy was distributed by The Refractories Institute on July 23, 1976 (Appendix B-2) to each member company. This illustrates the genuine concern to implement energy conservation programs, but also indicates the lack of specifics in actions to achieve energy conservation, by industry institutes.

4.3 EQUIPMENT/PROCESS ENGINEERING IMPLEMENTATION

This section sets forth the major factors involved in the implementation of technical improvements and utilization of improved equipment in the brick/ceramic industry. The means used by the industry are illustrated through several examples of successful market entry of new equipment and new technology.

4.3.1 RECOGNITION OF NEED FOR CHANGE

Operators (plant managers) are aware of the problem of operating costs vs. profit margin and of the major inefficiencies that exist with the present production processes. This is particularly true in the case of those companies that are firing ceramic products in periodic kilns. The escalating cost of energy and the difficulties (or potential difficulties) of securing sufficient quantities of energy have focused the attention of management on the firing process.

The primary requirements for the implementation of new capabilities in the brick/ceramic industry is that the process be sufficiently tested so the operators will have confidence in its contributed value, that the new capability will either lower operating costs and improve profit margin, or provide more assurance that necessary fuel supplies will continue to be available at costs that can be supported by the profit margin of the business. Operators of periodic kilns will be receptive to considering implementation of thermal energy storage systems in their plants if assured that the process is practical and economical. There are already serious concerns about the escalating cost and the questionable availability of energy for this industry.

4.3.2 DEFINITION OF CHANGE

Definition of a specific plan for change in the brick/ceramic industry starts with the identification of new equipment or technology with the potential for improving profit margins or providing protection for the existing profit margin. While anyone in a company with an understanding of equipment, technology, or engineering may initiate proposals for change in the operation to improve performance, a company large enough to have an engineering department places more specific responsibilities for process, technology and equipment improvements on the plant or process engineer. These people are responsible for incepting and maturing new ideas. Engineering consultants, design engineers, and vendors are also involved in promoting the use of new equipment and technology which promises to improve profit margins, often bringing these possibilities to the attention of company management.

4.3.3 CRITERIA FOR IMPLEMENTATION

The equipment or process must have substantial evidence of practicability and workability. If a company is to initiate a new process, evidence attesting to the feasibility of the equipment or process must pre-date implementation. This rule continues in force because a major change in process, even though subsidized in terms of actual equipment cost, can cause a loss in production that would cost many times the amount of the capital investment itself. Good management demands recognition of the impact of changes in equipment and process technology and the development of plans for the management of downtime or productivity loss. An example of this is companies providing materials for housing sometimes operate on a seasonal basis and can schedule major changes for the seasonal shutdown period.

4.3.4 EXAMPLES OF SUCCESSFUL MARKET ENTRY

The following case histories of successful market entries of new equipment and technology into the brick/ceramic industry illustrate how new equipment and technical processes have been designed, introduced, and accepted. Frequently the invention of new equipment or technology does not achieve acceptance and use until some relatively minor or peripheral development overcomes a shortcoming in the original idea and thereby makes the project practical. A number of instances are documented in patent records where useful inventions stagnated

for 50 years or more before development of an improvement in a detail permitted the original invention to become part of a practical process. The tunnel kiln was devised in principle as early as the end of the 18th century. It was tried a number of times afterwards, with dubious results, from then through until about 1920. It took the development of dependable electric motors and accurate pyrometer temperature indicators to provide the consistent operation and dependable control to make this kiln practical. The motors and pyrometers were in a sense quite incidental to the concept of the tunnel kiln itself, but the tunnel kiln concept was impractical until they were available.

4.3.4.1 The Fork Lift Truck

Until the second world war, little consideration was given to using forklift trucks in the face brick or refractory brick industries. Before, the standard method in the refractories industry of handling finished, burned brick from kilns to storage or railroad cars, was a four-man wheelbarrow crew. Incentive piece rates were paid for handling burned brick, and a four-man crew could move 16,000 bricks in 4-5 hours.

The gasoline-powered fork truck (Figure 4-3) was widely used during World War II. At the end of the war, the refractories industry started to make use of the fork truck to handle burned brick. One of the first plants to adopt this method was the Salina Pennsylvania plant of General Refractories Company. Here periodic kilns has been completely replaced in the 1920's by tunnel kilns and the trucks could move on level runways directly from the tunnel kiln cars' unloading station to storage, to railroad cars, or trucks for shipment. Bricks were handled on either single or double-face pallets (3' X 4') carrying approximately 500 bricks. Using the lift truck, the man stacking the brick on the pallet was the only brick handler. Brick were left on the pallet in storage and pallets were stacked 4-5 high in the storage shed. Brick could be handled by the lift truck alone from storage to railroad cars since the brick were shipped on the pallets. Brick were sometimes taken directly to railroad cars from the tunnel kiln car without being touched after loading onto the pallet. At piece rates, the man loading brick on pallets could handle up to 12,000 bricks/day. As a result the bricks were handled at a rate of 12,000 bricks/man, plus the part-time service of the man on the lift-truck. This compared with the former four-man crew rate of 16,000 bricks/day, or only 4000 bricks/man. The cost savings was obvious.

By 1950 almost all tunnel kiln refractory brick were handled by lift truck. The problems involving the initial cost of pallets and the return of pallets from the customer were an annoyance, but did not prevent the rapid adoption of the lift trucks throughout the industry.

Similar savings could be realized in refractory brick plants using periodic kilns except that the kiln doors were originally sized for the passage of a wheelbarrow less than 3' wide, and could not accommodate a lift truck without masonry changes to enlarge the doors. The adoption of lift trucks by periodic kiln plants was somewhat slower on this account, but by 1960 lift truck brick handling became common in these plants as well.

FIGURE 4-3. FORK LIFT TRUCK

The adoption of lift truck handling of burned brick by face brick plants followed a somewhat different pattern. The lower-priced face brick were not ordinarily shipped on pallets, and in the face brick industry a variety of ideas were used to arrive at a package that did not require a pallet. The standardized package was arranged so that spaces were left in the lower section for the fork tines of the truck to pick up the package while strapping held the brick together. Systems for unloading brick directly from the tunnel kiln cars into monorail carriers, or carousel carriers, provided the means for blending brick of different colors into a single package and delivery of the block of brick to automatic strapping stations.

The development of the automatically strapped brick package and labor saving monorail, or carousel carriers, for blending brick into uniform mixes of the different shades of brick occurred simultaneously.

Individual brick manufacturers in the Southeast and Southwest developed strapped facebrick packaging as early as 1957 and 1958. Initially, this was on a somewhat limited basis with each company having a different package. By 1961 the industry had come closer to agreement on the type of package and accepted the carousel, or monorail system, which delivered a block of brick to a strapping station to be bound into a package. By the mid-1960's nearly all brick companies had adopted the more or less standard package shown in Figure 4-4. This package is 11 bricks wide by 5 bricks long, with voids left for the forks of the lift truck, and held 500 bricks.

The system of handling brick packages on forks mounted on either a lift truck or on a crane was energetically promoted by the manufacturers as a means of saving labor in moving the manufactured brick and its delivery to the customer (7). Customers had an equal opportunity to save labor in unloading packages from trucks to the cars, but were slow to take advantage of the opportunity. Even now a number of end users do not use a lift truck for handling the brick between the truck or car and the wall where they will eventually be laid. By 1968 virtually every brick manufacturer was delivering brick in a standard package held together by metal strapping. The fork lift truck became the standard method of handling brick in the brick plant from the strapping machine to storage or to trucks for shipment. The peripheral developments of the package itself, and of combining the equipment, made the use of the lift truck possible for handling burned face brick.

Lift truck handling of unburned face brick for delivery to periodic kilns by lift truck followed still another path. The key factor here was the development of hydraulic operated gripper forks to pick up a stack of unburned brick without a pallet by gripping rows of brick at the bottom of the stack on which the rest of the cube of brick could be carried. (Figure 4-5). These cubes of brick were delivered by lift truck into the periodic kiln and set one upon another until the kiln was full. After firing, the same type of gripper fork was used with the lift truck to unload the cubes of brick and carry them to the monorail or carousel blending and packing station. After the brick were blended and strapped in packages for storage or shipment, a standard lift truck completed the burned brick handling operation. The development of a gripper-type of fork for use with the lift truck was not perfected until about 1951 by the Bickerstaff Company. Bickerstaff secured patents and

STANDARD SIZE BRICK

500 PACKAGE
(5 units of 100 each)

Face Dimensions: $2\frac{1}{4} \times 8$
Bed Dimension: $3\frac{11}{16}$

All dimensions are approximate.

FIGURE 4-4. STANDARD STRAPPED PACKAGE

Bickerstaff

MODEL 'D'

BRICK FORK

Bickerstaff Model 'D' forks are manufactured both in mechanical and hydraulic.

AUTOMATIC

The mechanical fork works automatically with the weight of the load. When the lift truck mast is raised the gripping takes place automatically. The greater the load the tighter the brick are held.

Each fork is designed for a particular operation taking into consideration the shrinkage and this feature gives you a better operation.

Mounting is simple and takes a matter of minutes to install.

Model 'D' Hydraulic Brick Fork

Model 'D' Mechanical Brick Fork

HYDRAULIC

Hydraulic forks have positive gripping regardless of the load. Long life cylinders with positive locking during gripping.

The Bickerstaff hydraulic brick fork was designed for applications requiring the handling of light loads. It will handle from two brick to capacity. These forks come equipped with quick-change couplings and can be mounted in one minute or less

Bickerstaff **MATERIAL HANDLING**

A DIVISION OF BICKERSTAFF CLAY PRODUCTS COMPANY, INC.
P. O. BOX 1178 • COLUMBUS, GEORGIA 31902 • 205/298-0455

FIGURE 4-5. GRIPPER FORK ATTACHMENT

licensed others to produce the gripper fork, but found acceptance of this piece of equipment mounted on the lift truck a problem (8). The difficulty was in convincing manufacturers that they could produce a good product and that brick would stand up in the kilns during firing without shifting, during the firing process when delivered by a gripper fork, and still be in shape to be unloaded from the kilns by this same equipment. Resistance was gradually overcome and by the early to middle 1960's the gripper fork had become standard equipment for setting brick in plants employing periodic kilns. The labor cost savings that resulted by using the lift truck with this gripper fork attachment gave additional impetus to the periodic kiln operation in face brick plants. Without the gripper fork lift truck setting operation, periodic kilns would have been abandoned much more quickly than has been the case. In 1971 the Bureau of Building Marketing Research affiliated with Brick & Clay Record Magazine, conducted a survey of lift trucks used in the heavy clay products industry. A questionnaire was mailed to 1000 plants. The following summary, Figure 4-6, is based on the returns from 96 plants. The survey demonstrates the broad acceptance of the lift truck in the industry.

Ninety-seven percent of the plants surveyed own one or more lift trucks. On the average, each owns 10.6 units.

The most popular lift truck size is 4000 pounds. The average size of the lift trucks reported is 4400 pounds.

Nearly half of the lift trucks owned are between three and five years old. The average is 6.3 years.

The average replacement age of the lift trucks owned by respondents is 6.1 years.

Nearly 40% of those surveyed plan to purchase new lift trucks during the next twelve months. An additional 30% plan to purchase some time during the next twenty-four months.

NUMBER OF LIFT TRUCKS OWNED

Of the 96 plants surveyed 93, or 96.9% own one or more lift trucks.

Together, these plants own 989 lift trucks for an average of 10.6 per plant.

SOURCE: The Bureau of Building Marketing Research
Research Affiliate of BRICK & CLAY RECORD Magazine
5 South Wabash Avenue
Chicago, Illinois 60603
September 1971

FIGURE 4-6. LIFT TRUCK USE - BRICK & CLAY RECORD SURVEY

To summarize, for handling refractory brick on pallets, standard off-the-shelf lift trucks were used. For face brick handling in tunnel kiln plants, again standard off-the-shelf lift trucks were used after a packaging system was developed. In periodic kiln plants special custom design gripper forks were required to make general adoption of the new equipment and process possible for both filling and emptying the kilns. Lift trucks began to be used in the industry starting about 1945. By the middle 1960's they had been completely adopted for brick transport operations. Key milestones are indicated in Figure 4-7. Management accepted the use of lift trucks in the brick/ceramic industry as soon as the peripheral developments made the system acceptable and usable. As long as the system could be depended upon to perform, it was easy to prove that the return on investment justified the purchase of the lift trucks.

FIGURE 4-7. MILESTONES OF IMPLEMENTATION OF FORK LIFT TRUCKS
BY THE BRICK/CERAMIC INDUSTRY

4.3.4.2 High Velocity Burner

The firing process in the brick/ceramic industry requires that the ware be set in kilns to allow hot gases to flow through this setting and transfer heat to each piece of ware by means of convection. Since the vitrification process involves the forming of a glassy matrix in the body of the ware, the ware softens having a reduced load-bearing capability. The amount of space that can be provided between the individual brick or pieces of ware is limited. There is a trade-off between the amount of space provided in the setting for each passage of hot gases and convection of heat to the ware, and the need to set the brick in the most stable arrangement with the least opportunity for marking between the courses as the ware goes through the minimum load-bearing point at the vitrification temperature. In practice the end result is that brick or other ceramic ware is almost always set more tightly in the kilns with less space between the pieces than would be ideal for maximum penetration of products of combustion through the setting. As early as 1930, efforts were made to modify the gas burners, then available, to a type that produced a high velocity stream of hot gases, to more readily penetrate the setting of brick and speed up the convective heat transfer to the ware. The operation of high velocity gas burners requires that combustion in the burner blocks take place at a pressure of several ounces per square inch. In 1930, the gas burners were not capable of sustaining this operation without serious physical deterioration of the burner itself.

In the early 1960's Bickley Furnaces developed, patented and commercialized the ISO-Jet burner for their proprietary kiln designs. This burner was capable of supplying a high velocity stream of hot gases with a large excess air capability. This process made possible the control of temperature of the hot gases from very low levels up to the maximum required temperatures with on-ratio firing. The burner was somewhat complicated and was not made available to other kiln designers, but the advantages of its use were well recognized. The success of the burner in the proprietary Bickley-designed kilns stimulated further efforts to develop a simpler burner.

In 1967 and 1968, two of the major burner manufacturers in the United States developed and began marketing dependable high velocity gas burners (9-12). The North American Manufacturing Company designed their Tempest burner, and the initial burner produced by Eclipse Fuel Engineering was called the #63 HVTA burner. These new burner designs used only gaseous fuel, either natural gas or LP gas, as most tunnel kiln and periodic kiln operations at that time were using gas. The initial applications of these burners were on new tunnel kilns. The ability of the burner to provide a high velocity stream of products of combustion, which penetrated the setting and radically improved the rate of heat transfer made the burners immediately successful. A representative of North American Manufacturing Company said that once dependable high velocity burners became available, their use spread through the brick/ceramic industry in a manner unique in their experience. In some cases fuel savings of up to 50% were realized. In most instances, the rate of travel of kiln cars through the kiln had to be increased to take full advantage of the penetration, entrainment and recirculation benefits afforded by high velocity burners (13). Tunnel kiln heat losses are relatively constant regardless of how much ware is being put through the kiln. Therefore, if other parts of the production

process can operate at a high production rate, firing the additional product through the tunnel kiln does not require additional fuel in proportion to the additional production (14). The increased production rate through the tunnel kiln becomes possible because the greater penetration and circulation by the high velocity of products of combustion produces a faster transfer of heat to the ware and temperature uniformity throughout the setting in less time than when penetration is not as thorough. In addition, kilns can be operated with less excess air and therefore less stack loss from the exhaust of heated excess air. This occurs because the high velocity jet, on leaving the burner, entrains with it lower temperature kiln atmosphere gases. This mixing of kiln atmosphere gases with the product of combustion, coming directly from the burner, lowers the temperature of the mixture so it is not at a dangerously high point when the combined mixture of gases impinges on the setting of ware in the kiln. Without this mixing by entraining kiln atmosphere in the products of combustion, the burners would have to be operated with a greater percentage of excess air simply to reduce the flame temperature to a point where it would not be dangerously above the temperature of the setting of ware.

The development of high velocity gas burners for tunnel kilns had a substantial effect on tunnel kiln design. For years producers of face brick wanted tunnel kilns with larger production volumes. Because of the limit of the load-bearing characteristics of the brick at high temperature going through the vitrification process, it was not possible to build higher kilns. At the same time because of technical and physical difficulties, it was impractical to build longer kilns, so few kilns have been built over 600 feet in length. The remaining option was to build wider tunnel kilns. Before the advent of high velocity burners, the only way to secure distribution of heat across a wide tunnel kiln was to fire the kiln from the top. This presented problems with the roof structure. High velocity burners made it possible to build kilns as much as 20 feet wide with good results (quality) and high production (capacity) from a kiln of a manageable length and a normal setting height.

In the 10 years since high velocity burners became commercially available as a tool for kiln designers, they have been almost universally adopted. Over the same period, burner manufacturers, kiln designers, and consulting engineers have been active in advocating the adoption of high velocity burners in existing tunnel kilns. Acceptance has been slower here because existing kilns are sometimes not as wide as the newer kilns and high velocity burners are not as necessary to penetrate the narrower setting. However, high velocity burners have been adopted by a substantial number of kiln operators for their existing kilns, particularly for use in the preheat section of the tunnel kilns where the lack of penetration of low velocity burners results in a serious lag in heating the center of the setting, and in temperature differentials between various parts of a single car, frequently as much as 400°F. Figure 4-8 shows a typical circulation pattern created in a tunnel kiln by the use of high velocity burners. Major increases in production rates of up to 30-40% have been possible on existing kilns with the replacement of the former low velocity burners with the high velocity type.

FIGURE 4-8. . GAS CIRCULATORY PATTERN WITH
HIGH VELOCITY BURNERS

Figure 4-9 shows a view of a typical high velocity burner with the restricted orifice burner block which produces the high velocity output of the products of combustion. The figure also shows a cross-section sketch of this burner.

In 1970 a demand developed for a dual fuel high velocity burner that would fire either gas or light fuel oil. Kiln operators were becoming subject to more interruptible gas contracts, or seasonal curtailments, and a few kilns were operating in locations where no gas was available. To provide such a burner the functioning of the oil burner itself had to be improved to minimize the danger of accumulation of carbon in the burner block when firing with fuel oil. Two of the major burner companies developed workable high velocity dual burners by modifying their standard low velocity nozzle mix type of burner. These have been applied in a number of operations. The burners function satisfactorily but require greater care in adjustment of the air-fuel ratio, and have not yet been widely adopted. A third burner company has been working since 1972 on development of a completely new, superior high velocity combination gas/oil burner; this burner is now in commercial use. Initial reports from the field indicate satisfactory operation is being achieved. At the same time, the burner company that first offered the modified existing nozzle mix type burner as a high velocity dual fuel burner is expecting to have a completely new dual fuel burner on the market with superior capabilities before the end of 1976.

Initially the industry thought high velocity burners would help continuous tunnel kilns only, however, in the last five years high velocity burners have been applied to both shuttle kilns and periodic kilns. A primary advantage of high velocity when applied to large volumes of setting in intermittent type kilns, including both shuttle and beehive kilns, is the ability of the high velocity burner to create recirculation of gases already in the kiln, through the setting of ware, and thereby accelerating the heat transfer process. The increase of circulation of kiln atmosphere through the ware is caused by the ability of the high velocity jet to entrain kiln atmosphere which has already passed through the ware and recirculate it, by the use of venturi blocks in front of the high velocity burners to aspirate and recirculate kiln atmosphere. Hendryx Engineers has developed a patented shuttle kiln design using a duct arrangement for bringing kiln atmosphere from the bottom of the setting back to the burner block, re-heating and re-injecting the atmosphere into the kiln through a venturi block to establish the maximum recirculation through the setting. With the use of this system the circulation advantages of tunnel kilns are available for periodic and shuttle kilns, in that more rapid heat transfer to the ware takes place, and the burners can be operated at higher flame temperatures. Their energy advantages are that they operate at lower quantities of excess air hence lower stack heat losses. These benefits accrue while the temperature of products of combustion emerging from the venturi block and impinging on the ware are kept within safe limits in relation to the temperature of the ware itself throughout the firing cycle. This application of a high velocity burner in the patented shuttle kiln design has been communicated to the companies in the industry both by presentation of technical papers at meetings of the American Ceramic Society, which were then published in the ACS Bulletin, (Appendix B-3), and by advertisement in the Brick & Clay Record (Figure 4-10).

Cross-Section Thru Typical High Velocity Burner

FIGURE 4-9 . TYPICAL HIGH VELOCITY BURNER

Down Draft Shuttle Kiln Saves 15 to 35% Fuel*

*(Based on actual comparative figures on production burns. Fuel savings in individual situations will vary depending upon operating conditions.)

Five other advantages include: faster firing; greater uniformity; even temperature in kiln; faster heat transfer, and efficient utilization of the car deck setting area.

The secret of this kiln's efficiency and low loss results is in the patented firing system and kiln design. Burners at the top of the kiln create pressure for down-draft movement and thoroughly mix the gases over the ware.

After the products of combustion make their initial pass through the setting, they are recirculated and reheated which results in economies and faster firing.

The downdraft firing produces the uniform transfer of heat to the ware which is so successful in periodic kiln firing.

We have worked out this method for all ceramics: brick, pipe, tile, flower pots, dinnerware, china, electrical porcelain, sanitaryware and art ware. We can save you fuel, space, rejects and give you lower all-over firing cost.

HENDRYX ENGINEERS

INCORPORATED

FIGURE 4-10. ADVERTISING OF HIGH VELOCITY
BURNER APPLICATION

Burner manufacturers do not have separate records of the numbers of high velocity burners sold to the ceramic industry from their total sales figures.

However, North American Manufacturing Company reports that after the current series of gas firing high velocity burners were first marketed in 1967; the first year they had significant sales volume was 1970. The growth rate since 1970 is shown in Figure 4-11. This growth is not limited to brick/ceramic industry sales, but can be considered representative of the rate of acceptance of the high velocity burner in these industries.

In summary the high velocity burner itself was primarily developed to meet a problem of the brick/ceramic industry. The burners became standard off-the-shelf hardware, but have been undergoing modifications to improve their capabilities for ceramic industry service. High velocity burners are used outside the ceramic field where heat penetration to a load of material is an important factor, or where a high volume of furnace atmospheric circulation around a body to be heated is needed. However, these other uses have not altered the basic design of the burners. The integration of the high velocity burner into the design of new continuous tunnel kilns took place almost immediately since the engineers and kiln designers had no difficulty in recognizing this improvement. The integration of the burner into the process as a part of a complete new tunnel kiln being supplied to a manufacturer caused no problems nor found resistance. The integration of the high velocity burner into existing tunnel kilns has been somewhat slower. Both the design engineers and vendors have made continuous efforts to inform kiln operators of the advantages of using the new burners. Here, as usual, it is necessary to provide evidence that the new burners will provide cost savings and reduction in the fuel needed. One of the primary ways high velocity burners reduce the fuel required per unit of production is by increases in kiln production capacity; a kiln operator may not be ready to adopt high velocity burners if his production requirements do not permit him to run the kiln at a higher operating rate, and thereby secure lower fuel consumption per unit produced. In addition, adoption of high velocity burners is affected by their being limited to the use of gas or #2 fuel oil. With the current widely advertised uncertainty of a firm supply and a predictable price for either natural gas or #2 fuel oil, brick manufacturers are delaying decisions involving investment that depends on these fuels. The absence of a reliable gas supply and the higher costs of fuels are inhibiting the adoption of means that could reduce the quantity of fuel used and increase the efficiency of the energy process. Despite these problems a major burner manufacturer reports that high velocity burners now comprise half of all industrial burners sold by that company.

4.3.4.3 The Insulated Thin-Wall Periodic Kiln

Babcock & Wilcox Refractories Division, a leading producer of insulating brick, led the step-by-step development of the thin wall, insulated, pressure-fired periodic kiln (15). The initial step was the use of insulating brick in only the crowns of periodic kilns. As early as 1940, insulating brick were installed in the crowns of three periodic kilns of the Alphonse Custodis Construction Company. No further use of insulating brick in kiln crowns was recorded by Babcock & Wilcox until 1948-49 when two different companies installed insulating

**Rate of Implementation of Gasfired High Velocity Burners
by Industry**

FIGURE 4-11. GROWTH OF NEW BURNER SALES

brick in the crowns of both rectangular and round down-draft periodic kilns. The results of these trials demonstrated fuel savings in the neighborhood of 20%. Starting in 1950, Babcock & Wilcox made a rapid penetration of the market with insulating brick for the crowns of periodic kilns. A tabulation made in 1957, recorded 257 periodic kilns with insulating brick crowns. About then, the use of insulating firebrick in sidewalls was initiated and 12 of the 257 kilns were constructed with insulating brick sidewalls.

During this time Babcock & Wilcox made available to brick and sewer pipe manufacturers, drawings and a design for a new kiln of quite different construction than the older heavy brick design, although the size and shape of the kiln remained very much the same. (Figure 4-12). The new Babcock & Wilcox design consisted of a 9" wall of insulating brick with temperature ratings of 2000-2300°F. The inside diameter of the kiln ranged between 30-50 feet. The outside of the 9" insulating brick wall was covered with 1" of insulating blanket refractory material and the external shell of the kiln was made of steel of a thickness between 7 gage and 3/16". The crown of the kiln was made of concentric rings of special key arch wedge crown brick usually of 2600°F rated insulating brick. The crown was 9" thick, the same as the walls. (Figure 4-13). This kiln design replaced kilns made with walls from 2-3 feet. thick built of heavy refractory brick and with crowns that varied from 12-18" in thickness of heavy refractories. (Figure 4-14). Babcock & Wilcox distributed detailed instructions on the design and construction of kilns to their specifications in order to promote the sale of their insulating brick.

Since the late 1950's the basic structural design of the insulating brick has remained the same, but substantial improvements have been made in the burner system and the operating procedures. The initial insulating brick kilns were fired in the same manner as the older heavy refractory brick kilns, ten to twelve fireboxes were located around the periphery of the kiln near the floorline. Firing was by natural gas in most cases. The burners were a simple atmospheric, inspirating type that fired into a space behind a rectangular or semi-circular bagwall that directed the products of combustion vertically upward to the crown of the kiln. There gases mixed in the space over the setting and flowed down through the setting under the natural draft provided by a stack. The stack was sometimes equipped with an exhaust fan or an injection type booster. The firing cycle on the initial kilns using insulating brick was usually the same as the firing cycle of kilns built of heavy refractory brick. As a result the only fuel saving was in the reduction of radiation loss and reduction in the heat once stored in the heavy refractory brick. Insulating brick substantially reduced the losses from these particular areas, but did not reduce other losses. Improvement in fuel economy was limited to about 20% or less.

The thin wall insulated kiln provided a substantial opportunity for major additional reductions in fuel consumption by making use of improvements that had been made in burners and firing procedures. The opportunity for improvement lay in the very long firing time that was still being used on periodic kilns, ranging from 5-10 days. As a result, the stack losses or radiation losses continued for this long period. If the firing could be accomplished in a shorter period of time, the same amount of heat would be needed to heat the ware as was required using the longer firing period, but the losses would be reduced in proportion to the reduction in the firing time.

FIGURE 4-12. THIN-WALL INSULATED PERIODIC KILN

Pomona's amazing new top fired periodic kiln.

FIGURE 4-13.

Typical Section Between Bag Walls of a 32'-0 I.D.

Insulating Firebrick Periodic Kiln.

FIGURE 4-14. HARDWALL PERIODIC KILN

The long firing time was necessary with periodic kilns using aspirating burners and natural draft stacks because with this equipment there was very little ability to draw combustion air into the kiln in the earlier part of the burn. The protection of the ware against damage resulting from high temperature gases passing over the ware when it was at a relatively low temperature required the use of excess air to keep the products of combustion within a safe temperature range in relation to the temperature of the ware in each stage of the firing process. Since the cold stack provided little draft, only a small amount of air could be pulled through the kiln and only a small amount of fuel could be burned while maintaining the necessary low flame temperature. As a result only a slow rate of heat application could be achieved during the early part of the burn and the entire firing time was extended. In the late 1950's the burner manufacturers were able to provide an improved nozzle mix burner with a sealed back which had the capability of operating at a high ratio of excess air so the burner could put out a large volume of products of combustion diluted with excess air to a low resultant temperature. This burner could be applied to the thin wall insulating brick kiln, and because of its sealed steel shell design, the kiln could be operated at a slight pressure without leakage. Therefore, the air supply capacity of the combustion air blower could be utilized to put a much larger volume of low temperature products of combustion and excess air through the setting at the earlier part of the burn. More gas could be burned while retaining the low temperatures required at this stage, many more BTU could be liberated, and the increased volume of products of combustion and excess air served to transmit heat to the setting by convection much more rapidly than older aspirating burners with stack draft could. The result of the use of this burner system has been a drastic reduction in firing time. Some kilns of this type fire for no more than 24-36 hours. The result of reducing the firing time increased the annual production capacity of each kiln. The kilns could be fired more times per year, and fuel consumption savings were greater than the original savings made by using insulation with the original long firing time.

In the last few years the high velocity excess air burner (reported on in Paragraph 4.3.4.2) has been used in a few periodic and shuttle kiln installations to produce a recirculation of kiln atmosphere through the ware. This recirculation of kiln atmosphere results in still further improvement of the convection heat transfer process from the kiln atmosphere to the ware and still further reduction in the time required to bring the ware to a final temperature. Fuel savings of up to 35% have been realized, in comparison with similar kilns without recirculation, thereby further improving the prospects for continued use of periodic kilns by the industry.

In summary, the development of the thin wall, pressure-fired, insulated periodic kiln was a step-by-step process involving a sequence of breakthroughs where the development of the kiln structural design was used with disassociated improvements in burner systems and firing procedures to achieve the full benefits in the combination. It is somewhat disappointing to note that many of the existing thin wall insulating brick periodic kilns are still operating with inspirating type burners with its longer firing cycle and greater fuel requirements, where ultra-conservative managers are reluctant to depart from the status quo, even though there is good evidence that a change will offer fuel savings.

4.3.4.4 Automatic Brick Handling

A case history of the development and implementation of automatic brick setting and unloading equipment for handling brick on and off of tunnel kiln cars has been provided by the Pearne & Lacy Machine Company. Manufacturers of competing equipment have not responded to the requests for information, but the Pearne & Lacy report accurately represents the history of the implementation of this new type of equipment by the industry. Because the Pearne & Lacy report, provided by Joseph A. Guzzetta, V.P., is representative and because it includes a number of independent comments based on this equipment designer's experience on brick industry characteristics, it is included here essentially intact (16).

"Pearne & Lacy Machine Company began to automate the manufacturing, finishing and handling of clay sewer pipe in the early 1950's. The clay sewer pipe industry was faced with competition from other materials, and rising costs due to the great deal of hand labor required to make and handle their product. The automation of this industry not only enabled them to manufacture their product with lower costs and reduced losses but provided them with a higher quality product. Over these early years we attended industry meetings such as the Structural Clay Products Division of the American Ceramic Society whose members included both clay sewer pipe manufacturers and brick manufacturers. In our contact with brick manufacturers at these meetings we learned that the brick industry was having problems with high costs of manufacturing and competition of other building products. There had been little change in the way brick had been manufactured from early times and it used a great deal of hand labor. In the early 1960's we conceived a method of automatically setting brick on kiln cars and presented these concepts to the brick industry at their meeting in 1963. There was little interest shown as the brick industry was not open to changing their old-fashioned methods. We were told that the brick would not stand up on the car without 'hand-tying' the brick and pushing the brick through wires for cutting would not give them the same quality brick. In other words, they were afraid to come out of the 'Stone Age' into the present. As the old methods had been successful, they did not want to change. In the meantime the cost of hand labor was rising and also was becoming difficult to obtain. In 1964 the management of Midland Brick Company in Chillicothe, Missouri, decided to automate their setting operation and ordered the first automatic setting machine in the U.S. This machine was placed in operation in 1965 and proved to be successful. Even though the machine had proved itself in actual plant operation, the rest of the brick industry was still apprehensive about making the change to automated setting. It was two years before the second machine was put into operation. All this time the labor situation was deteriorating,

and costs were rising and competitive products were dominating the market. By the end of 1967 six machines were in operation as the labor problems forced the industry to make the big step to automation. In the years following, most plants began to automate their setting. Labor was their big problem, and it was now apparent that setting machines could do the job that was required. The setting machines also improved as we learned what could and could not be done in the setting of brick, and improvements were added to the equipment plus versatility to enable the equipment to handle a wide range of products. During this same period we were developing equipment to automatically unload brick as it was apparent that if labor was a problem in the setting of the brick, it also would be a problem in the unloading of fired brick, which also used a great deal of hand labor. Brick plants were now much more open-minded concerning the automation of the unloading of brick. Automatic setting was successful and in most cases had improved the quality of their product and, rather than say it could not be done, their only question was how and when.

In 1969 the first automatic unloader was put into operation at Southern Brick, within a very short time after the successful operation of this equipment most plants began to automate their unloading. As with setting there has been constant improvement made to the equipment as both customer and manufacturer learned what the problems of unloading were. Unloading presented problems that were entirely different from setting. In automatic setting the product was under control at all times and was precisely located when marshalled to be set on the kiln car and its size was precise. Unloading presented an entirely different set of problems. The product that was uniform and precisely placed on kiln cars had been moved through the drying and firing process. The product now shrunk in size (sometimes non-uniformly), had moved from their original setting position and were not standing perfectly straight on the car. There were now broken or cracked brick, and they were now very abrasive to handle as compared to when they were in the green state. Automation is now an established fact in brick plants and it is our belief that we are now entering the second generation of automated brick handling equipment with new and improved kiln designs."

This report touches on the recognition of need in the industry for this equipment and the resistance to change that was encountered. The adoption of the equipment came when rising labor costs and difficulties in obtaining labor forced brick manufacturers into trying the equipment and finding solutions to problems in its use. Pearne & Lacy used meetings of the Structural Clay Products Division of the American Ceramic Society as a means

of communicating with brick manufacturers, both to secure clear information on the needs of the manufacturers and as a means of telling the manufacturers the capabilities and benefits the automatic handling equipment could provide. Numerous papers have also been presented by Pearne & Lacy at technical meetings as the equipment was put into use and more plants reported on its operation.

The equipment used to automatically set brick on tunnel kiln cars is shown on Figure 4-15 and the automatic unloading equipment is shown on Figure 4-16.

As in the case of the other examples of market entry of new equipment into the brick/ceramic industry, the acceptance of this new equipment depended to a substantial extent on the development of improvements in areas peripheral to the equipment itself. In this case improvements had to be made to secure more uniformity in the drying and firing operations so that the stack of brick would remain stable through these operations without shifting as the brick dimensions changed. These improvements were of great value in securing acceptance of the new equipment by this industry.

4.4 INDUSTRY PERSPECTIVE OF ERDA ON ENERGY CONSERVATION

Financial and technical support by ERDA will be needed to develop an energy conservation program involving thermal energy storage. The initial reaction of some managers in the industry when they received preliminary information on the TES project were impressions of doubt about its practicability. Assistance will be needed to show the practicality, workability, and cost/energy saving of the process with TES integrated into the kiln loop, and this information should be presented to top management in well-supported form to avoid the creation of initial adverse reactions.

4.4.1 FINANCIAL AND TECHNICAL SUPPORT

a. R&D

The brick/ceramic industry would expect ERDA, or some agency under contract to ERDA, to fund and staff any research and development efforts as they do not at present feel organized or financially prepared to support a major joint R&D effort.

b. Pilot Program

Companies in the brick/ceramic industry will require a convincing demonstration of the feasibility of TES from a pilot operation of sufficient magnitude to assure that the operation can be successfully scaled up to commercial levels.

4.4.2 SUPPORT WITH GOVERNMENT AGENCIES

a. Government Energy Policies

The industry would look to ERDA to take the lead in suggesting

FIGURE 4-15.

PEARNE AND LACY AUTOMATIC BRICK SETTING MACHINE

FIGURE 4-16.

PEARNE & LACY AUTOMATIC BRICK UNLOADING MACHINE

THE
PLATYPUS
PATENT N° 3,487,959

energy conservation incentives through recommendation of consistent policies on energy pricing and allocations, and to provide guidance and leadership in efforts to influence Congress and other cognizant government agencies dealing with energy matters to implement these policies.

ERDA should take actions that might bring about more clarity and less confusion or doubt by the manufacturers in the brick/ceramic industry, with regard to future costs and supplies of fuel. This would be most useful if an ERDA objective is to provide a climate of greater confidence on the part of the manufacturers towards taking action on energy conservation programs. This would be true both with regard to energy conservation involving a thermal energy storage system, as well as with regard to any other energy conservation program that calls for capital investment. Any capital investment must be amortized. The company must have confidence that it will have sufficient fuel to be able to continue productive operation with an adequate return for a long enough term to carry the amortization, before they will undertake a major capital investment. In promoting the implementation of TES, the capital cost of the system will be in competition with the capital cost of other ways of conserving fuel. With presently available technology and equipment, old periodic kilns could be and have been abandoned and replaced by tunnel kilns with well known fuel savings of approximately 50%. The capital cost of building a tunnel kiln could be a deterrent to widespread TES market success if the proposed thermal energy storage system has a capital cost which in relation to the quantity of heat the system will save, is greater than the capital cost of building a tunnel kiln. In relation to the quantity of heat the tunnel kiln would save the latter would be chosen, given justification for production capacity equivalent to periodic kilns.

b. Tax Incentives

Tax credits would be helpful in securing company commitments for major capital expenditures for the new equipment and technology. Performance improvement incentives would be of less value since the necessity for economic performance, which the companies already have, is a greater incentive to the adoption and efficient use of a program that offers cost savings, than a separate performance improvement program would be.

4.4.3 COMMUNICATIONS TO INDUSTRY AVAILABLE TO ERDA

The heavy ceramic industries using periodic kilns includes hundreds of companies. The 1976 Directory of Brick Manufacturers published by the Brick Institute of America (17), 175 Old Meadow Road, McLean, Va., 22101, lists 187 companies producing face brick with the addresses of their main offices and locations of their plants when a company has more than one manufacturing unit. The 1976 Directory of the Vitrified Clay Sewer Pipe Industry (18) put out by the National Clay Pipe Institute, 350 West Terra Cotta Avenue, Crystal

Lake, Ill., 60014, lists 24 companies manufacturing sewer pipe with their main office addresses, their division offices, individual plant locations, and with the names of officers and managers listed. The Directory of Membership (19) of The Refractories Institute, 1102 One Oliver Plaza, Pittsburgh, Pa., 15222, lists 62 companies as active members in the Refractories Institute with full details locating the home office, listing of officers and staff, listing of addresses of all plant and research locations. In addition, the Refractories Institute, 1972 Product Directory of the Refractories Industries (20), lists all manufacturers of refractory products at that time whether they were members of the Institute or not, and include details of the products produced by each manufacturer and the plant locations. Through use of these directories communication can be established with virtually all potential users of TES in the brick/ceramic industry by the methods described below.

Joint efforts should be set up between industry, trade associations or institutes, and ERDA, as soon as there is evidence that a specific thermal energy storage system has been developed, that the system will work, and the capital and operating costs can reasonably be expected to be within the financial capabilities of companies in the industry. This evidence could be presented 1) to the chief executives of the identified companies, 2) at one of the membership meetings of the institute, or 3) by initiating contacts through the executive secretaries of the institutes. The support of the chief executives of the companies making up the institute memberships, expressed through the support of the institutes, would be a major factor in securing acceptance of the program by industry. Joint efforts between ERDA and the industry institutes could then make use of all of the following means of communication, although these means could also be used without working through the industry trade institutes.

Technical papers should be delivered at meetings of the American Ceramic Society, the Plant Operators' Forum held annually in North Carolina, the Factory Operators' Meeting of the Refractories Institute and similar meetings of other organizations attended by industry engineers and operators. These technical papers should be published in journals such as the American Ceramic Society Bulletin, Brick & Clay Record Magazine, Ceramic Age Magazine, Ceramic Industry Magazine, and other similar publications. These publications will also reprint technical papers that are given at other technical society meetings. Advertisements should be run in trade magazines such as the Brick & Clay Record, Ceramic Age, Ceramic Industry, Industrial Gas, Industrial Furnaces, and other trade magazines widely read in the brick/ceramic industry.

In addition to these uses of technical journals and magazines, design engineers, and consultants, experienced and accepted within the industry, established vendors, can take the lead in directly contacting by phone, letter, or visits, key individuals in the companies that are prospective users of an energy conservation system. Finally, direct mailing can also be effective in reaching all prospective users and providing them with pertinent information, including the technical papers mentioned above.

The government has several additional means of spreading news and reporting to industry and the public on energy related matters, including the following:

The Government Printing Office (GPO), Superintendent of Documents, distributes all reports generated on all government sponsored programs resulting in a written report. The National Technical Information Service (NTIS) distributes reports of a technical nature on all subjects. Also has a weekly abstract publication of new reports available. NASA Scan is a vehicle by which international reports are contained in abstract form with information on sources, document identifications and pertinent ordering information.

The Census of Manufacturers reports on industry specific parameters including production output, cost accrual (raw materials and value added plus sales) and energy demands. This is the most comprehensive and complete source of industry energy data available. The data base extends back to the 1940's. Finally, the Department of Commerce/FEA Voluntary Industrial Energy Conservation Program produces quarterly reports on major industry segments energy use as reported by industry trade groups.

4.5 MARKETING ACTIONS AND SCHEDULE

The action program for introducing TES to the brick/ceramic industry is based on the following requirements:

1. The equipment and/or process must be shown to be practical and dependable by both R&D and consistent performance of pilot operation.
2. Operating costs must be shown to be competitive with alternate sources of heat energy available to the user, and the capital cost must be supported by a return on investment that can be amortized on a sound financial basis.
3. Adequate assurance must be given that sufficient energy will be allocated to the user so he can reasonably expect to be able to continue production through the time period required to amortize the capital investment.

The steps required to fulfill this program are fourfold; the first includes technical and physical actions to develop a pilot operation and the demonstration of a practical and financially feasible TES system. The second is the creation of a TES industrial energy conservation research and development facility. The third is the communication of the capabilities and advantages of the TES heat conservation system to the individual companies in the industry. The last is the securing of cooperation and support of government agencies in creating incentives for the use of TES energy conservation.

4.5.1 TECHNICAL AND PHYSICAL ACTIONS OF PILOT OPERATION PROGRAM

A program for implementation of TES in the brick/ceramic industry can be initiated at the point where R&D has produced a process and equipment ready to be put into pilot operation on a sufficiently large scale to provide assurance that full size commercial units can be expected to perform as well as the pilot unit. Based on this premise the actions required to

implement the pilot plant program are listed as follows to begin upon the completion of TES feasibility tests.

- a. Select representative applications.
- b. Design pilot plant.
- c. Secure quotation on pilot plant construction.
- d. Award contract for pilot plant.
- e. Construct pilot plant.
- f. Perform acceptance and startup of the pilot plant for a shakedown period.
- g. Forecast capital and operating costs of full scale unit.
- h. Demonstrate pilot plant to prospective users.
- i. Forecast heat recovery capabilities and efficiencies of a full scale unit in a refined economic and technical analysis.

4.5.2 CREATION OF TES R&D WITHIN AN INDUSTRIAL ENERGY CONSERVATION R&D CENTER

Development and implementation of TES in the brick/ceramic industry will require continuing technical guidance. As soon as TES feasibility tests are completed, the scale-up of the design to pilot operation, and subsequent scale-up from pilot operation to commercial operation will involve many technical decisions that will require R&D work. At an industrial energy conservation R&D center, which we assume will be designated possibly as a part of the national laboratories research and development activities, continuing TES R&D could provide these services and the technical evidence of TES capabilities for communication to potential users as pilot plant operation progresses. This industry energy conservation R&D center could carry out joint ERDA/industry association research programs as opportunities or problems arise in the implementation of TES energy conservation projects.

4.5.3 COMMUNICATION TO THE INDIVIDUAL COMPANIES IN THE INDUSTRY

ERDA can initiate publicity on the objectives and expectations of TES through the Refractories Institute, the Brick Institute of America, and the National Clay Pipe Institute as soon as sufficient technical evidence and confidence in the technology and equipment exists to justify the actions. These organizations can be used to reach the chief executives of the member companies, as well as to all levels of plant operations personnel.

ERDA can promote the presentation of technical papers at annual and semi-annual meetings of professional societies, such as the American Ceramic Society, which are attended by recognized engineering and research consultants. Arrangements can be made for the publication of technical papers in the American Ceramic

Society Bulletin, Brick & Clay Record, Ceramic Industry, Ceramic Age, Industrial Gas, and Industrial Furnaces. As soon as a company has a full-size commercial unit in good operation, follow-up technical papers should be presented and published, giving actual commercial performance data.

Advertisements by designers, manufacturers, and vendors of TES equipment can be encouraged jointly sponsored and/or subsidized in the Brick & Clay Record, Ceramic Age, Ceramic Industry, The American Ceramic Society Bulletin, Industrial Gas, and Industrial Furnaces. Finally, ERDA can initiate the distribution of information and reports through the government documentation network. Joint reports from ERDA, and industry associations to their members will be useful in reporting progress and developments in the implementation of TES-based energy conservation systems.

Brick/ceramic industry management normally communicate the application of new equipment or processes within their own organizations. This approach is used in order to be as certain as possible that the proposed new equipment or process is practical, workable, and can be understood and operated by their plant operators. In view of this situation, plant engineers should be invited to attend short courses explaining the use and implementation of TES systems and provided with a TES design handbook to assist them in applying this equipment to individual plants.

4.5.4 CREATION OF INCENTIVES FOR USE OF TES THROUGH GOVERNMENT AGENCIES AND ACTIONS

ERDA can take action to create incentives for the brick/ceramic industry to use the TES conservation systems by encouraging development of consistent policies, and by influencing Congress and governmental agencies involved in energy to implement these policies. This can be achieved by securing from the companies, through trade associations or directly, information on the present range of costs and availability of various fuels in all geographical areas and using this as a basis on which to develop policies and recommendations.

Recommendations to the FEA on allocations and pricing of energy to the brick/ceramic industry could provide more assurance of dependable energy supplies to companies which use TES effectively. ERDA could also make recommendations to the FPC regarding correction of imbalances and inconsistencies in the energy supply and rates to the brick/ceramic industry. Congress should be approached with a plan for the provision of tax incentives in support of capital investment in TES energy conservation equipment by individual companies.

4.5.5 SCHEDULE OF INTEGRATED ACTION

Figure 4-17 charts a schedule for commercialization of a thermal energy storage system for use with periodic kilns in the brick/ceramic industry.

ACTION PLAN AND SCHEDULE

A program as comprehensive as this can be extremely effective in the brick/ceramic industry. A review of the section concerning implementation of new equipment and technology shows that in each case there was initial reluctance to accept new equipment or technology followed by rapid acceptance when it was proven and convincingly communicated to a company's management. The above market plan will provide a practical program, directed to the end-using industry, of the actual benefits demonstrated by TES. This industry/government approach would be expected to significantly enhance commercialization.

4.6 SECTION 4 REFERENCES

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SECTION 5

DEMONSTRATION PROGRAM

5.1 GENERAL TEST PLAN

The importance of a well-planned, relevant demonstration program cannot be overstressed. TES is a technology untried in industrial process settings and has unproven operational reliability when associated with plant production schedules. In this first test of TES in an industrial application, the demonstration must be designed to accomplish the following objectives:

1. Verify the energy conservation potential to periodic kiln applications.
2. Validate the system analysis techniques developed to assess thermal energy savings.
3. Identify the requisite design provisions required within a TES system to properly integrate with the specific firing equipment.

There are other lesser goals such as developing a TES hardware envelope, establishing man-machine requirements, evaluating candidate media materials and control strategies, and, of course, optimizing TES performance. These and other criteria play a role in generating the framework for a responsive test program; however, the first steps are to validate the basic process interfaces and energy consumption impacts under a production line environment. The TES prototype hardware must therefore be capable of meeting these overall requirements. This section discusses the test objectives, process interactions, test program flow and preliminary test measurement definitions.

5.1.1 TEST PROGRAM OBJECTIVES

The TES demonstration phase will establish a fundamental baseline of conventional kiln thermodynamic performance, including flue and cooling gas flows over the kiln operating cycle. The impact of TES integration will then be evaluated through an extensive series of test runs with the prototype device employed in production line duty cycles. These tests include both functional assessments as well as diagnostic trials to better understand the design implications of optimizing TES system configuration and performance. Specifically, detailed tests should be structured to:

- Quantify kiln and TES gas heat flows and temperature profiles.
- Qualify materials, controls, and sensors for heat recovery and TES equipment applications.
- Optimize TES operational strategies for maximizing energy efficiency.

- Confirm TES to process interface points.
- Solidify a TES design approach for a full-scale pilot plant program.
- Determine further R&D requirements for advanced systems as well as a state-of-the-art device.

5.1.2 PROCESS INTERACTIONS

As a result of the applications study (see Section 2), the TES demonstration should look at each of the three cited heat loads - kiln pre-heat, combustion (or secondary) air pre-heat and ware drying, both singly and in normally-occurring combinations. This will develop balanced heat input-output criteria, thermal energy storage capacity, heat exchange rates and sequencing scheme(s) associated with normal plant operations. A major consideration in establishing process interfaces with the TES equipment is to assure compatibility with the majority of plants using periodic kilns, which is the market to be served by this TES application.

Interface commonality in plants where beehive shuttle and other periodics are employed can be confidently specified. These include the combustion air supply manifolds, secondary air supply networks in more modern kilns, and exhaust flues in all kilns. Often, the exhaust flue contains louvers, or other outside air intakes, to cool the hot gases in order to protect downstream components such as stack fans from exposure to high temperatures. With a heat recovery device in the loop, this provision is provided by the TES. For supplying heat to the dryer(s), the existing gathering flue in plants where cooling gas can be routed to the dryer is available. In the other cases, an insulated duct similar to the type used to channel tunnel kiln cooling gases to a dryer will be required.

The demonstration program has been formulated to take advantage of two small shuttle kilns located in two plants of the Glen-Gery Co., headquartered in Reading, Pa. These shuttles are sized at 1500 and 4500 bricks, respectively. Their firing curves are shown in Figure 5-1. As would be expected the basic curves are similar, differing only in the time axis. These shuttle kilns are metal-jacketed IFB lined with standard inspirating natural gas-fired burners. The York kiln is side-fired while the Reading equipment is bottom fired. The drafts are also different in that the Reading device uses an upflow pattern to an overhead stack, while the York kiln is designed with a more conventional underfloor flue. Structural, mechanical, thermal and power interfaces to these kilns and plant systems are convenient and adaptable to the TES demonstration. These and other facility provisions are discussed in Section 5.3. The use of either of these kilns provides an opportunity to demonstrate a prototype TES serving one full-scale (though small capacity) kiln. The final selection of shuttle kiln is dependent upon facility availability and plant operating capacities at the time of the test program. Both plants are easily accessible to visitors and working personnel from the project team company locations.

FIGURE 5-1. KILN CYCLE: TIME/TEMPERATURE CURVE FOR BRICKS (GLEN-GERY KILNS)

5.1.3 TEST PROGRAM FLOW

After the TES prototype, facility, and test equipment are installed in the initial phase of the demonstration program, a series of confidence checks, inspections, and loop tests must be made preparatory to operating the system. The test flow would follow the pattern shown in Figure 5-2. The equipment and facility will be subjected to "bottom-up" inspections, checkout and tests leading progressively to systems interface and operability checkouts. Each level of acceptance will build confidence which will culminate in "all-up" trials of the in-place equipment, facility provisions and test systems. Upon completion of the installation and interface inspections and checkouts, the likely progression of tests are as shown below in Figure 5-3. These evaluations would provide the basis for extension of the TES experimental device to a pilot plant scale project.

FIGURE 5-3. TEST PROGRAM OVERVIEW

1. Checkout and Calibration of Test Equipment
 - Instrumentation and sensors
 - Interconnects and data loggers
2. Baseline Shuttle Kiln Nominal Performance
 - Temperatures - control point, stack flue (TES interface)
 - Gas flows - fuel input, stack flue, combustion air input
 - Time response characteristics
3. Integrated TES-Kiln Operations
 - Heat balance
 - Storage efficiency
 - Duty cycle and in-line performance
 - Materials - flue gas compatibility
 - Optimized operating sequence
4. Test Program Evaluation
 - TES performance comparative analysis
 - Process-TES interface design approach
 - Operational strategies
 - Maintenance and servicing requirements
 - Scale-up criteria for pilot/commercial units

FIGURE 5-2. TEST FLOW.

5.1.4 TEST PARAMETERS AND MEASUREMENTS

Areas of interest focus on the input-output conditions of the TES device and supporting components, the test shuttle kiln and the dryer (or dummy dryer load). Figure 5-4 shows the basic integrated system, the normal directions of flow and the instrumentation placement locations around the circuit. Section 3 analyzed the different operating strategies of the system depending on the kiln firing (or cooling) position through its cycle and the TES demands to be served. The sensor locations shown in the figure represent the minimum complement of performance data parameters required to evaluate the TES device in the system, and provide a representative set of readings for internal TES operations. Although it is likely that additional intelligence involving diagnostic assessments in the TES is warranted, the overall system parameters are well represented by the sensing requirement shown in the figure. Each measurement is further delineated in Table 5-1.

5.2 PROGRAM PLAN FOR TES PROTOTYPE DEMONSTRATION

The proposed demonstration configuration is to be scaled to one of the two shuttle kilns described in Section 5.1. During this phase of the TES program, General Electric maintained close ties with the Glen-Gery Corp., one of the largest, and most energy conservation conscious brick manufacturers in the country. To establish scaling criteria and specific conceptual design approaches, Glen-Gery worked with GE to establish feasibility of using their facilities and small shuttle kilns. Their interest and active participation allowed commitment of the plants and kilns identified in Section 5.1.2.

The proposed pebble bed TES concept is a compromise of the spatial (volume) constraints normally larger (and heavier) in sensible heat systems, a near-term technically achievable design, and the desire to force a state-of-the-art advancement using one of the several investigated latent heat concepts with their attendant space/weight advantages and concentrated heat capacity advantages. The pebble bed allows ERDA to initiate a conservative hardware program for a process industry with a least risk, cost-effective solution using a current design and off-the-shelf equipment approach. As a baseline of departure, the pebble bed is very similar to present cooling functions in kilns and can be easily understood and integrated with the skills and operations in today's operating VCP plants. For these reasons, GE has developed a program to accomplish this first, most important step, with the cooperation of Glen-Gery.

The broad program plan presented herein develops the shuttle kiln/TES concept from its present status as presented in Section 3 to a completed prototype TES device. The program plan includes provisions for support systems and facilities, process integration, facility modifications to accept the TES equipment, and the required testing provisions. This latter item includes a test console with data recording, instrumentation and controls for the impacted process, and test equipment. Cable troughs and fluid system loops are also considered and planned. The proposed plan includes functions to accomplish the express objectives of 1) validating TES performance and energy savings, and 2) verify analytical approaches for TES design. These functions are defined in Figure 5-5.

SCHEMATIC
OF
INTEGRATED SYSTEM'S PERFORMANCE
THERMAL ENERGY STORAGE SYSTEM

FIGURE 5-6

TABLE 5-1

PARAMETER NO.	LOCATION	UNIT(S)	TYPE	PARAMETER	INTERVAL	NOTES
TEMPERATURE						
1	KILN CHIMNEY (CONTROL POINT)	OUTLET TEMPERATURE	A	AMBIENT-2400°F	15 MIN.	
2	FLUE (NEAREST KILN)	FLUE GAS HEAT CONTENT TEMPERATURE PREP OR FLUE	A	300-2200°F	15 MIN.	
3	BURNER (OR SECONDARY) AIR INLET	INLET AIR ENERGY CONTENT	A	AMBIENT-1000°F	15 MIN.	WITH P2, P2
4	YES INLET-DISCHARGE NETWORK	GAS COMPOSITION INTO YES	A	AMBIENT-600°F	5 MIN.	WITH P4, P4
5	YES INLET-CHARGING NETWORK	ENERGY INPUT POTENTIAL	A	300-1800°F	5 MIN.	WITH P6, P5
6	YES OUTLET-CHARGING NETWORK	HEAT REJECT	A	<600°F	5 MIN.	16 + 15.25 HEAT INPUT TO YES
7	YES INLET	HEAT FLOW/STORAGE PATTERNS	A	AMBIENT TO 1700°F	1 MIN.	DETECT CHANGE, IND, BREAKTHROUGH, THERMAL ENERGY STORAGE INVENTION
8		SATURATION COMPOSITION (AED BREAKTHROUGH)	A			
9		CHARGING/DISCHARGING RATE AND PATTERN	A			
10		THEORY ENERGY DISTRIBUTION	A			
11	YES OUTLET- DISCHARGE NETWORK	YES HEAT OUTPUT THERMAL STABILITY	A	300-1200°F	5 MIN.	WITH P5, P4
12	DRYER AIR INLET	YES ENERGY INTO DRYER	A	300-500°F	15 MIN.	WITH P5 (FBI BALANCE WITH P03)
FLOW						
1	FUEL SUPPLY MANIFOLD	ENERGY INPUT KILN	S	0-3500 CFH	30 MIN.	WITH P1
2	KILN COMBUSTION (OR SECONDARY) AIR SUPPLY MANIFOLD	INLET AIR MASS FLOW	S	0-60,000 CFH	30 MIN.	WITH P2
3	DRYER FUEL INLET	ENERGY INPUT-DRYER	S	0-1500 LPH	15 MIN.	WITH P3
4	YES INLET-DISCHARGING NETWORK	INLET GAS MASS FLOW	A	0-65000 CFH	15 MIN.	WITH P4
5	YES INLET-CHARGING NETWORK	INLET GAS MASS FLOW	S	0-65000 CFH	30 MIN.	WITH P6
PRESSURE						
1	FUEL SUPPLY MANIFOLD	ENERGY INPUT-KILN	S	0-2 PSI	30 MIN.	WITH P1 (ALTERNATE: 10% PER 0% EQUIV.)
2	KILN COMBUSTION (OR SECONDARY) AIR SUPPLY MANIFOLD	INLET AIR MASS FLOW	S	0-15 PSI	30 MIN.	WITH P2
3	DRYER FUEL INLET	ENERGY INPUT-DRYER	S	0-2 PSI	15 MIN.	WITH P3 (ALTERNATE: EQUATION OR EQUIV.)
4	YES INLET-DISCHARGE NETWORK	INLET GAS MASS FLOW	A	0-6" H.C.	15 MIN.	WITH P4
5	YES OUTLET-DISCHARGE NETWORK	PRESSURE DROP ACROSS YES	A	0-6" H.C.	15 MIN.	WITH P4
6	YES INLET-CHARGING NETWORK	INLET GAS MASS FLOW	S	0-6" H.C.	30 MIN.	WITH P5
OTHER						
O ₂	FUEL STACK	PURGEY LACUS AIR	N	0-2%	30 MIN.	
A1	YES INLET HEAT- REJECTING INLET	HEAT FLOW (1) DRYER HEAT	S	100	15 MIN.	CONSTANT FLOW CONDITION

N - NORMALLY

S - SEMI-AUTOMATIC

A - AUTOMATIC

TES DESIGN AND PROTOTYPE DEVELOPMENT

Plan Functions

- Iterate TES Prototype Design Concept
 - System size/scale definition
 - Subsystem design
- Procure/Build and Test TES Prototype
 - Design studies
 - Hardware fabrication/procurement
 - Assembly and test
- Facility Preparation
 - Modifications plan
 - Special provisions for test/evaluation
 - Process interfaces for prototype evaluations
- Special Studies
 - System safety
 - Applicable codes and standards
 - Subsystem tests

FIGURE 5-5

To execute these challenges, GE has structured a set of tasks allowing ERDA to continuously review the program status and measure progress with funding expenditures through a series of interim milestones. These tasks are shown in Figure 5-6 and scheduled in Figure 5-7. The twelve-month program is divided into a detailed design definition phase (the first six months), highlighted by a Critical Design Review at the six month point, followed by a fabrication/procurement and test phase in the second six months. Workshops and periodic ERDA reviews are interlaced into the Program Management task along with the customary progress report documentation requirements. These workshops serve as a vehicle to allow early recognition of this application by industry and governmental agency representation, in concert with the proposed commercialization program presented in Section 4.

PROGRAM SCOPE

TASK 1. FINAL SYSTEMS DEFINITION

- 1.1 Trade-offs and Selection
- 1.2 Design Scale/Size and Performance Analysis
- 1.3 Subsystem Interfaces and Subsystem Specification
- 1.4 Supporting Test Program
- 1.5 Safety, Handling and Test Procedures

TASK 2. DETAILED SUBSYSTEM DESIGN

- 2.1 TES Media and Containment
- 2.2 Heat Exchangers and Components
- 2.3 Instrumentation and Controls
- 2.4 Integration of Facility and TES

TASK 3. FACILITY MODIFICATIONS

- 3.1 Demonstration Site Preparation
- 3.2 Process Interface Modifications
- 3.3 Test Facility Design

TASK 4. PROGRAM MANAGEMENT

- 4.1 Reports
- 4.2 Inter-agency and Contractor Coordination

FIGURE 5-6. PROGRAM TASKS

PROGRAM SCHEDULE

FIGURE 5-7

LEGEND:

- P - PRELIMINARY
- F - FINAL
- I - SITE INSPECTION
- S - PROGRAM STATUS
- W - WORKSHOP

5.3 DEMONSTRATION SITE ALTERNATIVES

The Glen-Gery Corporation has cooperated and provided guidance to the program through the participation of their technical staff and advice of production and operations executives. Also, virtually unlimited access was granted to several of the operating plants from which equipment operation and process relationships were observed and kiln performance data was recorded and transmitted to GE.

Apart from direct participation, as consultants to this effort, the Glen-Gery facilities were noted to include potential for implementing a TES feasibility demonstration, using one of several shuttle kilns located at the York and Reading, Pennsylvania plants. These kilns are relatively small (1500-4500 brick capacity) and used for specialized drying and firing requirements. However, their thermal cycle and fuel consumption patterns are much the same as the larger periodic kilns extensively analyzed in Section 3. The following descriptions further develop the TES-facility possibilities for the demonstration program considering either the Reading or York plants.

5.3.1 READING DIVISION

At the Reading Division plant in Reading, Pennsylvania, a DFC (Denver Fire Clay) commercially available under car, program-controlled up-draft kiln used for drying and firing approximately a four (4) ton load of face brick is available. The kiln is located adjacent to an existing tunnel kiln and its fired ware storage tracks. This shuttle kiln has its own kiln cars and requires rehandling of the ware from a cube or pallet to the kiln car.

In Figure 5-8, an elevation of the kiln and the proposed TES unit are shown to scale. The plan view is Figure 5-9.

Through a series of dampers and duct work, a heat storage and recovery system is possible at any stage of the drying and firing cycle. Of particular note in this application is the addition of side ports that will permit heat introduction from the TES unit prior to lighting the burners. The side port locations will require mounting the TES unit overhead to permit kiln car passage in and out of the kiln. The existing exhaust hood will have to be modified to adjust the admission of ambient air to control the temperature of the exhaust gases being cycled to the TES unit. Adequate area exists along the tunnel kiln wall for placement of the control panel.

5.3.2 YORK DIVISION

At the York Division plant in York, Pennsylvania, a Glen-Gery designed shuttle kiln utilizing standard six-wide tunnel kiln cars, side fired with down-draft air flow and program controlled, is available for drying and firing approximately a twelve (12) ton load of face brick. This shuttle kiln is about three times the size of the Reading Division unit. The kiln is located in an open floor space area between the existing kiln control room

FIGURE 5-8. READING PLANT SHUTTLE KILN-
TES DEMONSTRATION : ELEVATION

5-16

FIGURE 5-9. READING PLANT SHUTTLE KILN-TES DEMONSTRATION: PLAN VIEW

- and the gas producer. This shuttle kiln utilizes standard tunnel kiln cars the product can be transferred throughout the plant for manufacturing through shipping without rehandling the ware.

In Figure 5-10, an elevation of the kiln and the proposed TES unit are shown to scale. The plan view is Figure 5-11.

As in the Reading Division layout, a series of dampers and duct work make a heat storage and recovery system possible at any stage of the drying and firing cycle. This application, however, more closely approximates the large commercial down-draft kilns common in the refractory industry. The air flow pattern is down-draft in the kiln through underground flues to the exhaust stack. The TES unit is integrated with the underground flues as shown in Figure 5-10. The only kiln modification is the addition of the side ducts for recycling stored heat prior to lighting the burners.

It is of particular importance to note that this kiln is constructed of insulating fire brick with a flat suspended arch which will enable modifications to be made without difficulty. Space is available in the existing kiln control room for placement of the control panel.

Summarizing, the demonstration and test program defined in this section is a practical, easily realized step towards developing industry interest in TES potentials, advancing TES equipment design to a first stage of development, and in integrating a TES with a full-scale operating kiln in an on-line function. The detailed program is straightforward, has been coordinated with a large brick manufacturing company to assure the credibility of the chosen approach, and employs a synthesis of state-of-the-art design and equipment capabilities.

FIGURE 5-10. YORK PLANT SHUTTLE KILN-TES
DEMONSTRATION: ELEVATION

FIGURE 5-11. YORK PLANT SHUTTLE KILN-TES
DEMONSTRATION: PLAN VIEW

SECTION 6

APPENDICES

APPENDIX A

- A-1. LIST OF CONTACTS AND SURVEY RECIPIENTS**
- A-2. SURVEY QUESTIONNAIRE SAMPLE**
- A-3. GE SURVEY DATA - PERIODIC KILNS:
ENERGY CONSUMPTION AND POPULATION**

APPENDIX A-1

BRICK/CERAMIC INDUSTRY SURVEY RECIPIENTS AND CONTACTS

1. COMPANIES

<u>NAME</u>	<u>LOCATION</u>
Resco Products, Inc.	Conshohocken, Pa.
Interstate Brick	West Jordan, Utah
Lava Crucible Refractories	Zelienople, Pa.
Refractories Division - H.K. Porter	Pittsburgh, Pa.
Orton Ceramic Foundation	Columbus, Ohio
General Clay Products	
Watkins Brick Co.	Birmingham, Ala.
Glen-Gery Corp.	Reading, Pa.
Louisville Fire Brick Works	Louisville, Ky.
Sherwood Refractories, Inc.	Cleveland, Ohio
Miller Tile Co.	Chatsworth, Ill.
Shenango Refractories	New Castle, Pa.
Bartley Crucible & Refractory Co.	Trenton, N.J.
A.P. Green Refractories Co.	Mexico, Missouri
Acme Brick Co.	Fort Worth, Texas
Zedmark, Inc.	Valencia, Pa.
Basic Refractories	Cleveland, Ohio
San Valle Tile Kilns, Inc.	Los Angeles, Calif.
Griffin Pipe Products Co.	Milledgeville, Georgia
U.S. Concrete Pipe Co.	Ocala, Fla., and Uhrichsville, Ohio
Universal-Rundle Corp.	New Castle, Pa.
General Porcelain Co.	Trenton, N.J.
Georgia Sanitary Pottery, Inc.	Atlanta, Ga.
Woodbridge Sanitary Pottery	Woodbridge, N.J.
Westinghouse Electric Corp.	Derry, Pa.
Wisconsin Porcelain Co.	Sun Prairie, Wisc.
Joslyn Manufacturing & Supply Co.	Lima, N.Y.
Frankoma Pottery, Inc.	Gapulpa, Okla.
Nelson McCoy Pottery Co.	Roseville, Ohio
The Mock and Son Co.	Cleveland, Ohio
Globe Refractories	Newell, West Va.
Wellsville Fire Brick Co.	Wellsville, Missouri
Continental Ceramic Corp.	Biglerville, Pa.
Hull Pottery Co.	Crookville, Ohio
Marion Brick Corp.	Marion, Ohio
Kilgore Ceramics Corp.	Kilgore, Texas
Monarch Tile Mfg. Inc.	Marshall, Texas
Frame Brick & Tile Co.	Anniston, Alabama
Taylor, Smith & Taylor,	
Div. Anchor Hocking	Chester, West Va.
Champion Spark Plug Co.	Detroit, Michigan

<u>NAME</u>	<u>LOCATION</u>
American Olean Tile Co.	Lansdale, Pa.
The Homer Longhlin China Co.	Newell, West Va.
Winburn Tile Mfg. Co.	Little Rock, Ark.
Ceramo Co., Inc.	Jackson, Missouri
Kasten Masonry Sales, Inc.	Jackson, Missouri
Mid-State Tile Co.	Lexington, North Carolina
Continental Clay Products Co.	Kittanning, Pa.
Syracuse China	Syracuse, N.Y.
Michigan Brick	Coruma, Michigan
Stark Ceramics, Inc.	Canton, Ohio
Stangl Pottery Co.	Trenton, N.J.
Universal Clay Products Co.	Sandusky, Ohio
Inland Refractories Div. - Inland Enterprises	Cleveland, Ohio
Akron Porcelain Co.	Akron, Ohio
Structural Stoneware, Inc.	Minerva, Ohio
Martin-Marietta Chemicals Refractories Div.	Hunt Valley, Maryland
Christy Firebrick Co.	St. Louis, Missouri
Allied Tile Co.	Zanesville, Ohio
Gem Refractories Plant -Ferro Corp.	Sebring, Ohio
The Wahl Refractory Products Co.	Fremont, Ohio
Allied Mineral Products, Inc.	Columbus, Ohio
Southern Plant - Ferro Corp.	Liverpool, Ohio
AFC Corp.	Canfield, Ohio
Jamestown China Co.	Mt. Clements, Michigan
Refractory Products Co.	Carpentersville, Ill.
Verson	Dallas, Texas
Industrial Ceramic Products, Inc.	Columbus, Ohio
AVX Ceramics	Myrtle Beach, South Carolina
Laurel Brick & Tile Co.	Laurel, Mississippi

2. TRADE ASSOCIATIONS AND JOURNALS

American Ceramic Society	Columbus, Ohio
The Refractories Institute	Pittsburgh, Pa.
Brick and Clay Record - Cahners Publications	Denver, Colorado
National Clay Pipe Institute	Crystal Lake, Ill.
Brick Institute of America	McClean, Va.

3. EQUIPMENT MANUFACTURERS AND CONSULTING ENGINEERS

Harrop Ceramic Services, Inc.	Columbus, Ohio
Bickley Furnaces, Inc.	Philadelphia, Pa.
Swindell-Dressler, Co.	Pittsburgh, Pa.
Hendryx Engineers, Inc.	Pittsburgh, Pa.
Ajax Electric Co.	Philadelphia, Pa.
Pennwalt Chemicals	King of Prussia, Pa.

NAMELOCATION

Hooker Chemical and Plastics Co.
Comstock & Wescott, Inc.
North American Mfg. Co.
Eclipse Fuel Engineering Co.
Babcock & Wilcox

Niagra Falls, N.Y.
Cambridge, Mass.
Cleveland, Ohio
Philadelphia, Pa.
Canton, Ohio

4. UNIVERSITIES AND AGENCIES

North Carolina State University
Department of Commerce -
Census of Manufacturers

Durham, North Carolina
Washington, D.C.

APPENDIX A-2. SAMPLE OF SURVEY QUESTIONNAIRE

SPACE DIVISION

GENERAL ELECTRIC COMPANY VALLEY FORGE SPACE CENTER
(MAIL: P. O. BOX 8555, PHILADELPHIA, PENNSYLVANIA 19101), Phone (215) 962-2000

SPACE SYSTEMS
ORGANIZATION

May 10, 1976

Gentlemen:

In March, 1975, the Energy Research and Development Administration (ERDA) contracted with the General Electric Company to perform an economic and technical feasibility study of thermal energy storage as a means of energy conservation. The study was concerned with revealing the areas in which thermal energy storage systems can provide measurable benefits in terms of more efficient use of natural gas, oil, coal and electrical energy within the residential, commercial and industrial market sectors. In the industrial sector, which consumes about 40% of total U. S. energy, emphasis was placed on examining those industries exhibiting time-variant thermal energy demands, a primary determinant of thermal energy storage applicability.

Several promising applications emerged from this effort, including the use of thermal energy storage in conjunction with periodic or shuttle kiln operations in the Brick/Ceramic/Refractory industries. General Electric has recommended to ERDA that this application be furthered to a demonstration stage of development as a first priority in exploiting this new capability. ERDA has concurred and is supporting the next study phase which involves establishing the energy impacts, generating system designs and advising ERDA on the best route to a commercially viable product.

To assure incorporation of the several different viewpoints, the end user at the plant, the process design engineer and the equipment manufacturer are being surveyed relative to their individual perspectives on the energy conservation potentials offered by thermal energy storage. Your cooperation in filling out the attached questionnaire will greatly assist this program. Your industry will benefit from development of a thermal energy storage concept, particularly in light of natural gas supply scarcity and costs. Reply can be anonymous, but location of plant, by state, would be helpful. If additional information is desired, do not hesitate to call or write.

Very truly yours,

R. L. McCarthy

Robert L. McCarthy
Energy Systems Engineer

Attachments

BRICK/CERAMIC/REFRACTORY MANUFACTURING FACILITIES

QUESTIONNAIRE

1. COMPANY NAME* _____
 ADDRESS _____
 CITY, STATE, ZIP _____
 RESPONDENT - TITLE _____

* NOTE - If anonymity is desired, please indicate only the state(s) of your plant locations and complete the questionnaire

2. Type of product produced at your facilities: (check all applicable)

SIC	TITLE
☐ 3251	Brick and Structural Clay
☐ 3253	Ceramic Wall and Floor Tile
☐ 3255	Clay Refractories
☐ 3259	Structural Clay Products nec.
	Others - List Below

3. Please indicate the fuels used for your kiln/dryer processes and annual consumption of each

TYPE	APPROXIMATE ANNUAL CONSUMPTION
☐ Natural Gas	_____ Thousand Cubic Feet
☐ Oil	_____ Barrels
☐ Coal	_____ Tons
☐ Electricity	_____ Kilowatt Hours

4. Do you have flexibility in the choice of the major fuel used or are there constraints? (Example - Can only maintain product purity with natural gas)

☐ FLEXIBLE - Function of (Circle Applicable Items)
Price, Availability, Product Manufactured,
Other _____

☐ INFLEXIBLE - Must Use _____

DUE TO:

5. Types and Quantities of Kilns utilized

	Total Number	Average Number in use
SHUTTLE		
OTHER PERIODIC		
CONTINUOUS		

NOTE: If shuttle or periodic kilns are not used in your operations, please stop at this point and return the questionnaire. This is valuable information to this study.

6. Shuttle Kiln Information

If shuttle kilns are utilized in one or more of your manufacturing facilities, please complete table 1.

7. Periodic Kiln Information

If other types of periodic kilns are utilized in one or more of your manufacturing facilities, please complete table 2.

TABLE 1 SHUTTLE KILN INFORMATION

LOCATION OF FACILITY	NO. OF SHUTTLE KILNS	TYPE OF WARE FIRED	AVG. CAPACITY (TONS OF WARE) PER LOAD	AVG. ENERGY CONSUMPTION (BTU/CYCLE)	FUEL TYPE USED	TOTAL PRODUCTION PER KILN (TONS PER YEAR)

TABLE 2 OTHER PERIODIC KILN INFORMATION

LOCATION OF FACILITY	NO. OF PERIODIC KILNS	TYPE OF WARE FIRED	AVG. CAPACITY (TONS OF WARE) PER LOAD	AVG. ENERGY CONSUMPTION (BTU/CYCLE)	FUEL TYPE USED	TOTAL PRODUCTION PER KILN (TONS PER YEAR)

8. Figure 1 presents example firing curves for shuttle and periodic kilns. Alter as necessary to show typical curve(s) for shuttle and/or periodic kilns used in your facilities. Label areas where individual processes occur, i.e., drying, firing, cooling.
9. Are waste gases from periodic or shuttle kilns used for other thermal processes?
- ☐ NO
- ☐ YES - Explain uses and limitations

APPROXIMATE PERCENT RECOVERY _____

10. If the answer to the previous question is no, why is waste heat not being recovered?
- ☐ No known capability to recover for later use
- ☐ Recovery equipment is too costly
- ☐ Potential savings not worthwhile
- ☐ Impurities in gas
- ☐ Other _____
11. Are there plans for future waste gas heat recovery?
- ☐ No
- ☐ Yes Method(s): _____
- Uses: _____
- Time Frame:
- ☐ Within one year
- ☐ 1 to 2 years
- ☐ 2 to 5 years

KILN CYCLE : TIME/TEMPERATURE CURVE FOR BRICKS

FIGURE 3

12. Are any other efficiency improving devices or techniques being considered?

☐ No

☐ Yes

Type	Estimate of Percent Energy Saving	Time Frame For Implementation

13. What are the present determinants of periodic/shuttle kiln use in your operations?

☐ Special Orders

☐ Very high production rate, beyond capacity of continuous kilns alone

☐ Very low production rate, below continuous kilns economical operation level

☐ Certain product types require periodic kilns

☐ Other - Explain:

14. Is there a definable "strategy" or operations plan associated with periodic/shuttle kiln use?

☐ No

☐ Yes - Briefly Describe:

15. What is the future of periodic/shuttle kilns in your operation?

16. Please draw a rough layout indicating typical locations of kilns (all types) and other thermal processing equipment in relation to each other. Show approximate dimensional relationships.

17. A Thermal Energy Storage (TES) device can recover heat lost during the kiln firing profile for later use. This could be in a subsequent kiln cycle or in another ongoing thermal operation. Potential energy recovery is estimated at up to 35% of presently rejected heat.

Assuming that a TES device was economically attractive and could be easily integrated into your operations, how would your equipment use and purchase plans change? (Check all applicable)

- ☐ No change
- ☐ Increased use of shuttle and/or periodic kilns
- ☐ Would purchase additional shuttle/periodic kilns
- ☐ Would defer purchase of continuous kilns
- ☐ Would change product mix to utilize benefits of periodic/shuttle kilns

18. If economically priced TES systems became available, when would your operations consider their use?

- ☐ Immediately
- ☐ Within 2 years
- ☐ 2-5 years
- ☐ 5-10 years
- ☐ _____ years
- ☐ Not interested in TES
- ☐ New equipment preferred over modifications

APPENDIX A-3

PERIODIC KILNS -
ENERGY CONSUMPTION AND POPULATION
GE SURVEY DATA

BRICK - SIC 3251
KILN INVENTORY

SURVEY

PLANT NUMBER	CONTINUOUS KILNS	SHUTTLE KILNS	OTHER PERIODICS
1	-	-	8
2	11	-	4
3	2	-	16
4	2	1	-
5	4	-	-
6	3	-	-
7	3	1	-
8	2	-	6
9	1	-	4
10	2	1	-
11	1	-	-
12	4	-	-
13	2	2	-
14	2	-	13
15	10	-	-
16	3	-	-
17	2	-	6
18	1	-	-
19	2	-	-
20	2	-	7
21	1	-	-
22	2	1	7
23	2	-	4
24	1	-	-
25	2	-	9
26	1	-	-
27	2	-	-

TOTALS

CONTINUOUS 105
SHUTTLE 9
OTHER PERIODICS 116

LITERATURE

PLANT NUMBER	CONTINUOUS KILNS	SHUTTLE KILNS	OTHER PERIODICS
28	-	1	-
29	1	-	-
30	2	-	-
31	-	2	-
32	3	-	-
33	1	-	-
34	1	-	-
35	2	-	-
36	2	-	-
37	1	-	-
38	2	-	-
39	1	-	2
40	1	-	-
41	-	-	11
42	-	-	2
43	1	-	-
44	2	-	-
45	1	-	-
46	1	-	-
47	1	-	-
48	1	-	-
49	1	-	-
50	3	-	-
51	3	-	-
52	2	-	-
53	2	-	-
54	1	-	-
55	1	-	-
56	4	-	8
57	1	-	-
58	1	-	-
59	2	-	-
60	1	-	9

REFRACTORIES - SIC 3255, 3297
KILN INVENTORY

SURVEY

PLANT NUMBER	CONTINUOUS KILNS	SHUTTLE KILNS	OTHER PERIODICS
1	-	2	-
2	2	1	8
3	3	-	18
4	3	-	26
5	4	-	-
6	1	-	-
7	-	1	1
8	3	1	12
9	3	-	11
10	1	-	-
11	-	-	5
12	2	1	11
13	2	1	3
14	3	-	-
15	2	-	7
16	11	-	-
17	2	-	5
18	3	-	-
19	-	1	1
20	2	2	-
21	4	-	-
22	2	1	9
23	2	-	5

LITERATURE

PLANT NUMBER	CONTINUOUS KILNS	SHUTTLE KILNS	OTHER PERIODICS
24	-	-	19
25	3	-	-
26	-	1	23
27	-	3	8
28	-	1	17
29	2	-	6
30	2	2	-
31	2	-	-

TOTALS

CONTINUOUS	64
SHUTTLE	18
OTHER PERIODICS	195

CLAY PIPE - SIC 3259
KILN INVENTORY

PLANT NUMBER	CONTINUOUS KILNS	SHUTTLE KILNS	OTHER PERIODICS
1	1	5	1
2	2	1	-
3	-	1	2
4	-	-	15
5	2	-	15

PLANT NUMBER	CONTINUOUS KILNS	SHUTTLE KILNS	OTHER PERIODICS
6	3	-	-
7	-	1	2
8	-	-	2
9	1	-	2
10	1	-	17

TOTALS

CONTINUOUS	10
SHUTTLE	8
OTHER PERIODIC	56

SHUTTLE KILNS

BRICK

PLANT	ANNUAL ENERGY BTU
A	.5 X 10 ⁹
B	25.0 X 10 ⁹
C	1.9 X 10 ⁹
D	3.6 X 10 ⁹

AVERAGE
11.2 X 10⁹ BTU

REFRACTORIES

PLANT	ANNUAL ENERGY BTU
A	12.1 X 10 ⁹
B	80.3 X 10 ⁹
C	4.5 X 10 ⁹
D	11.3 X 10 ⁹
E	16.0 X 10 ⁹

AVERAGE
12.7 X 10⁹ BTU

CLAY PIPE

PLANT	ANNUAL ENERGY BTU
A	28.2 X 10 ⁹
B	32.7 X 10 ⁹
C	47.1 X 10 ⁹

AVERAGE
30.5 X 10⁹ BTU

OTHER PERIODICS

BRICK

PLANT	ANNUAL ENERGY BTU
E	17.5 X 10 ⁹
F	35.1 X 10 ⁹
G	28.8 X 10 ⁹
H	21.7 X 10 ⁹
I	17.3 X 10 ⁹
J	34.9 X 10 ⁹
K	10.1 X 10 ⁹
L	10.1 X 10 ⁹
M	19.0 X 10 ⁹
N	27.8 X 10 ⁹
O	25.1 X 10 ⁹
P	28.4 X 10 ⁹
Q	25.1 X 10 ⁹

AVERAGE
21.5 X 10⁹ BTU

REFRACTORIES

PLANT	ANNUAL ENERGY BTU
F	22.8 X 10 ⁹
G	10.0 X 10 ⁹
H	24.0 X 10 ⁹
I	19.3 X 10 ⁹
J	20.0 X 10 ⁹
K	14.0 X 10 ⁹
L	13.0 X 10 ⁹
M	5.0 X 10 ⁹
N	22.0 X 10 ⁹
O	8.3 X 10 ⁹
P	16.0 X 10 ⁹
Q	58.0 X 10 ⁹

AVERAGE
15.8 X 10⁹ BTU

CLAY PIPE

PLANT	ANNUAL ENERGY BTU
D	12.9 X 10 ⁹
E	43.2 X 10 ⁹
F	19.2 X 10 ⁹
G	31.0 X 10 ⁹

AVERAGE
17.0 X 10⁹ BTU

Note: Averages do not correspond to numerical average of numbers shown due to varying number of kilns per plant and the statistical methods employed.

ANNUAL ENERGY CONSUMPTION - PERIODIC KILNS
FROM GE SURVEY

APPENDIX B

- B-1. ECONOMIC COMMENT - MELLON BANK
- B-2. LETTER ON THE ENERGY SITUATION -
THE REFRACTORIES INSTITUTE
- B-3. ARTICLE ON KILN USING HIGH VELOCITY BURNERS¹

ECONOMIC COMMENT

Economics Office — Mellon Bank Pittsburgh, Pennsylvania

JULY 16, 1976

THE SPREADING EXPANSION

*As measured by percent change in Gross National Product
1976 estimated by Mellon Bank

Led by the impressive expansion of business activity in the United States, the economic recovery abroad has begun to take hold in an equally convincing manner. Using indices of industrial production in the major developed countries as a convenient common measuring rod, gains over the latest three months for which data are available now show advances exceeding those registered in the United States—with the one exception of the United Kingdom. Compared to the U. S. gain of 9.8%, recent annualized rates of increase range from 10.1% for Canada to an unsustainable near-50% for Italy.

According to Form. The recovery abroad so far has proceeded according to the expectations of most ana-

lysts. In mid-1975 when it became apparent that the U. S. was pulling out of its cyclical low point, observers suggested that it would take roughly six months for Western Europe and Japan to exhibit a similar turnaround. This now appears to have been the case, although the exact timing varies from country to country.

As in the United States, most of the recoveries abroad have been highlighted by a resurgence in consumer confidence and spending, with the construction and capital goods industries taking a back seat to other sectors. In the case of Japan, however, export demand—chiefly from the U. S.—has more than made up for continuing softness in domestic markets. Indeed, the Japanese

Subject matter continued on last page

APPENDIX B-1

THE REFRACTORIES INSTITUTE

1102 ONE OLIVER PLAZA

PITTSBURGH, PA. 15222

412-281-6787

OFFICE OF THE
EXECUTIVE SECRETARY

July 23, 1976

To the Official Representative of Each Member Company
and
Members of the Energy Committee

Subject: The Energy Situation - June 1976

The seriousness of our national energy supply situation is clearly stated in the attached articles. The Energy Committee refers this information to you for background.

The Institute, through its members, has recognized the critical energy situation since 1972 and has attempted to point out the need for conservation and good energy management throughout our industry.

In 1973 the first energy survey of our industry was conducted. It was updated in 1975. The members of The Institute and other refractory producers are continuing to monitor their consumption. Conservation programs of a formal nature are becoming widespread in our industry.

The attached articles point out the absolute necessity of our industry, along with others, to redouble their conservation efforts and to continue to monitor their accomplishments. Participation in The Institute's continuing survey of energy consumption by all refractory producers is the industry's way of voluntarily demonstrating the concern that is felt for the energy problem.

Also enclosed is a more detailed statement entitled "Energy and America" that will be proposed to members of the National Industrial Council for approval as background information on the subject with very general suggestions of what a sound national energy policy should include.

A comment on the oil company "Divestiture issue" by Treasury Assistant Secretary Gerald Parsky is enclosed.

Will you please consider these thoughts and pass along your comments regarding your specific situation to your Senators and Congressmen in hopes that a better overall National Energy Policy will be devised.

The Refractories Institute
Energy Committee

Encl.

APPENDIX B-2

Operating Performance of a New Shuttle Kiln Design

GORDON C. FAY*

Hardyck Engineers Inc., Pittsburgh, Pa

SHUTTLE KILNS have been used for a considerable time but are under continuing development to improve firing time, fuel usage and temperature uniformity throughout the setting. The following is a description of the design features of such a kiln and preliminary information on operating results.

A major reason for comparatively high fuel cost in shuttle kilns is that most of them operate with a single pass of the hot gases over the ware. Any heat not transferred from the kiln gases to the ware in that single pass is lost up the stack. To date, shuttle kilns designed for a high turbulence in the kiln and for exhausting through the bottom have tended to be somewhat complicated and usually more expensive than the updraft shuttle kiln, but even these units are essentially single pass kilns.

The new shuttle kiln design is based on a full downdraft kiln operation rather than updraft or side draft, with several passes of the kiln gases over the ware before they are exhausted out the stack. This design provides two advantages: 1) The downdraft design is the best way of insuring uniform heat treatment of the ware through the kiln. This design achieves the full downdraft with recirculation without requiring underground flues or high temperature exhaust fans. 2) The kiln is nearly as simple in design as the common updraft shuttle kiln.

The new design uses cars with a standard girder and deck tunnel kiln car top design widely used for many years in tunnel kilns where firing is done under the car deck with the gases flowing up through the deck and setting. In this design with downdraft operation (Fig. 1), gases flow down through the car deck exactly as if it were the floor of a periodic kiln. The gases are then exhausted from between the girders under the car deck through ports in the kiln sides below deck levels where burners would have been installed if this were a cross section of a tunnel kiln equipped for firing under the deck. With this arrangement, the sandseals and seals between the ends of the cars can be kept tight with a minimum opportunity for leakage either way through the bottom of the cars.

This design uses another standard procedure in that the burners are located high in the wall and fire into the space over the setting exactly as is done in insulated round downdraft periodic kilns using excess air pressure firing. Considerable experience has been accumulated in this type of firing, and there is general agreement that gases from the burners will mix thoroughly in this space above the setting and flow in a uniform downdraft manner through the setting under the slight pressure produced by the combustion air blower supplying the burners.

By using so-called pressure firing on this shuttle kiln design, no fan is required other than the combustion air supply blower. This blower can be operated to maintain a pressure of a very few hundredths of an inch of water in the upper part of the setting, and essentially a neutral pressure or a low draft situation at the car deck level. Exhaust gases are collected in a horizontal flue at the car deck level which connects with ports opposite the spaces between the girders. This flue is arranged to exhaust through stacks on each end, or four stacks on the corners of the kiln (Fig. 2). These stacks can be short since they are not required to produce any substantial amount of draft.

The very important recirculation of kiln atmosphere gases at all

The operating performance, on a production basis, of a new design of fast firing recirculating down draft shuttle kiln which was described in a paper given in 1973 is reported. Operating characteristics are described and the kiln performance is evaluated in terms of uniformity of burn, firing time and fuel economy.

Fig. 1 Section of kiln showing recirculation

Fig. 2 Plan section of kiln showing deck, exhaust ports and stack arrangement

stages of the burn is obtained by providing vertical ducts, or a hollow wall from the horizontal exhaust flues up to a space in front of each burner high in the sidewall. With this provision of returning kiln gases to the burners, high velocity excess air burners are used with a Venturi block mounted to aspirate the kiln atmosphere which has been drawn up through the individual flues to each burner, and reject it into the setting.

Therefore, it is possible to operate the kiln with less excess air and a higher flame temperature than would be possible if the burner products of combustion were going directly into the setting without being mixed with kiln atmosphere in the Venturi blocks. Better fuel economy will result since less excess air has to be heated and eventually lost up the stack at any given kiln temperature.

It is important that a high volume of kiln gases be circulated through the setting. Since rapid heat transfer to the ware is ensured, firing time is reduced with resulting reduction in fuel consumption. Conversely, when a lesser volume of these gases is circulated, the ware is heated more slowly, especially in the lower, colder parts of the setting. This results in a longer firing time and higher fuel consumption.

*Member the American Ceramic Society

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Gordon C. Fay

Gordon C. Fay is president of Hendryx Engineers Inc., Pittsburgh, Pa. He obtained a B.S. from Pennsylvania State University in 1933 and attended the 33rd advanced management program of the Graduate School of Business, Harvard University in 1958. Before joining Hendryx, Mr. Fay was with Harbison-Walker Refractories Co. and General Refractories Co.

Fig. 3. Shuttle kiln with loaded car in place.

Figure 3 is a photograph of the finished kiln set with refractory brick. The kiln in operation was designed to fire refractories in the 2500°–2900°F range. The figures given are a report of the most recent burns on this kiln. Comparisons between this kiln and others can vary widely since so many circumstances can vary from product to product and from plant to plant. The comparisons used are the best available based on operating results from a similar car type kiln fired with the same type setting, the same products, to the same temperature using a car of the same deck area.

The downdraft recirculating shuttle kiln on its most recent burn was fired to the same temperature as the comparison kiln with a reduction of 20% in the firing time. Metered fuel consumption indicated a reduction of $\approx \frac{1}{2}$ per ton of ware set. The car for the downdraft recirculating shuttle kiln was set with $\approx 20\%$ more weight than the single pass type kiln used for comparison. The new kiln did not require provision of space for firing lanes across or around the car as was required on the older kilns. Also some additional weight was set on the car by setting higher than was usual on the older kiln.

It is believed that 15–20% of the reduced fuel consumption was due to the recirculating design which provided the volume to bring about a faster transfer of heat from the kiln atmosphere to the ware. Faster completion of firing means the unavoidable stack and radiation losses went on for a shorter time, resulting in less loss overall. An estimated 10% of the reduced fuel consumption resulted from more ware being fired on the same cardeck area, with no increase in stack or radiation losses over the losses that would be normal with a lesser load.

The kiln is equipped with uv scanner type flame safety on all burners. It operates with automatic ignition of pilots and automatic control of temperature throughout the heating and cooling cycle. Air volume supplied to the high velocity burners is fixed and temperature is controlled by modulating gas only during the heating cycle. Temperature of cooling is controlled by the same instrument automatically operating the damper on the combustion air supply fan on the cooling portion.

During a recent burn, when the kiln had reached the final firing (soaking temperature) and was being held at this temperature on the crown couple by automatic controls, the volume of gas fuel continued to drop even though the crown couple maintained the same temperature. Less fuel was required to maintain full temperature in the circulating kiln atmosphere as the ware in the bottom of the setting came closer to the final temperature. In a single pass kiln, fuel required to maintain the crown couple temperature would remain the same regardless of the temperature at the bottom of the setting. As the temperature of ware at the bottom came closer to the final temperature, stack losses would increase since no further use of heat could be made after the products of combustion made their one trip through the setting.

Operating results of the new kiln appear to confirm the principles on which the design was based. Additional data are required to substantiate these results. A measurement of the volume of gases being recirculated at various stages in the burn would be supporting evidence for the fuel consumption figures. □