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A Study of Brick-Making Processes along the Texas Portion of the U.S.-Mexico Border: Senate Bill 749

Border Affairs Division

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

A Study of Brick-Making Processes along the Texas Portion of the U.S.-Mexico Border: Senate Bill 749

Prepared by
Border Affairs

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1. EXECUTIVE SUMMARY

In 2001 the 77th Texas Legislature passed Senate Bill 749 (SB 749), which requires the Texas Commission on Environmental Quality (TCEQ) to conduct a study of brick kilns near both sides of the border between the Texas portion of the U.S.-Mexico border. SB 749 also requires the TCEQ to produce a report by January 1, 2003 for the governor, lieutenant governor, and speaker of the House of Representatives, with recommendations on processes to decrease air pollution emissions from brick-making kilns.

Specifically, SB 749 requires the TCEQ to:

- conduct a study of the brick-making processes of brick production facilities near both sides of the border between Texas and Mexico, in cooperation with the Joint Advisory Committee for Improvement of Air Quality;

- survey current fuel sources for kilns, including the use of scrap wood and sawdust, tires, and other inefficient or highly polluting fuels;

- solicit the advice of experts from institutions of higher education, government, and industry of the United States and Mexico on efficient processes and fuels for maintaining proper temperatures for brick production, while minimizing emissions of air pollutants;

- consider the information collected in the study and make recommendations on efficient processes to decrease air pollutant emissions from brick-making kilns; and

- not later than January 1, 2003, issue a report to the governor, lieutenant governor, and speaker of the House of Representatives that summarizes the information and conclusions of the study, and highlights recommendations.

To present the proposed method for undertaking the study required by SB 749, the TCEQ staff met with legislative staff and members of a binational entity officially recognized by the federal governments of the United States and Mexico. This entity is the Joint Air Quality Advisory Committee for the Improvement of Air Quality in the El Paso, Texas/Ciudad Juárez, Chihuahua/Doña Ana County, New Mexico Air basin (JAC).[1] TCEQ officials presented the proposal to the JAC at meetings on December 13, 2001, and April 24, 2002.

Based on input received, the TCEQ initiated the study by reviewing past and current research efforts on brick-making processes of brick production facilities near both sides of the border between Texas and Mexico, focusing on the Paso del Norte area. There were no brick manufacturers with emissions from the Texas side of the border in the El Paso area (Nettles, 2002a), nor anywhere else along the Texas border outside of El Paso (Nettles, 2002b).

Using information obtained from this process, the TCEQ circulated a draft report among members of the JAC, whose members include experts from institutions of higher education, government, and industry of both the United States and Mexico. Based on comments the TCEQ obtained from the JAC, the report was finalized for distribution to the governor, lieutenant governor, and speaker of the House of Representatives.

Efforts to reduce air pollution from the Ciudad Juárez brick kilns initially began in the early 1990s. Three groups have been researching methods of constructing brick kilns to make them more efficient by improving the combustion process and reducing fuel requirements. By modifying the kiln design and improving efficiency, an 82 percent reduction in particulate emissions has been achieved, and an overall reduction in emissions of 54 percent.

Following are the primary recommendations from this study on efficient processes to decrease air pollutant emissions from brick-making kilns along the border between Texas and Mexico.

- **The principal recommendation is to continue to encourage and support the implementation of the new kiln technology in Ciudad Juárez**, using either the Marquez Kiln or the Environmental Brick Kiln. Both of these kiln designs accomplish improvements in fuel consumption for all brick making of this nature taking place in Mexico. In addition, the designs of the Marquez Kiln and data from testing of this kiln show a vast improvement over the current cube-shaped design, which emits great amounts of particulate matter, carbon monoxide, and other pollutants. Also, the benefits of using improved combustion sources made of native construction materials with construction processes known to the brick makers will allow for a much easier transition to the new kiln designs.

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[1]The JAC was institutionally created in Appendix I to Annex V of the Mexico-United States Agreement for Cooperation for the Protection and Improvement of the Environment in the Border Area, commonly known as the La Paz Agreement. The full agreement can be viewed at **http://www.epa.gov/usmexicoborder/2001/ef.htm**.

- **We do not recommend using cleaner-burning fuels as the most cost-effective means of reducing brick kiln emissions.** Fuels, such as natural gas or propane or liquified petroleum gas (LP gas) potentially could help reduce emissions. However, experience with these fuels shows that they are a less effective way to reduce emissions than other approaches. The main deterrent is the elevated cost that generally prices these fuels out of the reach of brick makers (Blackman, 1998). Improved combustion efficiency with cheap fuels is the most practical solution to reduced emissions.

- **We recommend the continued discouragement of the use of such fuels as used oils and scrap tires, which may not fully combust in the brick kiln.** This is the current position of the JAC and the various levels of Mexican government.

2. Introduction

The Federal Clean Air Act (FCAA) directed the EPA to establish national standards for commonly occurring air pollutants that pose threats to public health. These National Ambient Air Quality Standards (NAAQS) constitute national levels for acceptable concentrations of six specific pollutants in outdoor air: ground-level ozone, particulate matter with an aerodynamic diameter of 10 micrometers or less (PM_{10}), lead, nitrogen dioxide, sulfur dioxide, and carbon monoxide. These six pollutants are called "criteria pollutants." Once an area has violated a criteria pollutant air quality standard, the EPA can designate the area as "nonattainment" for that pollutant. The El Paso area, the only area in Texas that is currently designated "nonattainment" for more than one pollutant, is currently designated nonattainment for ozone, PM_{10} and carbon monoxide.

El Paso's air quality situation is complicated by its location. The region sits in an air basin, with the Franklin Mountains trending in a north-south direction, dividing El Paso in two, and with the Juárez Mountains trending east-west in the southern part of Juárez. Frequent temperature inversions cause pollutants to become trapped within the basin. To further improve air quality in this binational airshed requires cooperation from the two countries.

In 1996, the Joint Advisory Committee for the Improvement of Air Quality in the El Paso, Texas/Cd. Juárez, Chihuahua/Doña Ana County, New Mexico Air Basin (JAC) was created to address air quality in the Paso del Norte airshed. The JAC is a binational group formally recognized by the federal governments of the U.S. and Mexico. The JAC works to address these common air quality issues on a binational basis.

Brick kiln emissions in the Paso del Norte air basin have been one of the air quality issues noticed by residents of this binational community. Nearly 335 brick kilns are located in Ciudad Juárez. Besides producing bricks, the kilns also generate emissions of certain pollutants including PM_{10}, carbon monoxide, nitrogen oxides, and volatile organic compounds. The JAC studies the problem of pollutants emitted from these brick kilns and lists this as a project in the JAC strategic plan.[2]

During 2001, the 77th Texas Legislature passed Senate Bill 749 (SB 749), authored by Senator Eliot Shapleigh, requiring the Texas Commission on Environmental Quality (TCEQ) to:

[2] The actual wording in the JAC Strategic Plan is "Regulate the use of fuels and promote cleaner technologies in the fabrication of brick" (UTEP, 2002).

- conduct a study of the brick-making processes of brick production facilities near both sides of the border between Texas and Mexico, in cooperation with the Joint Advisory Committee for Improvement of Air Quality;

- survey current fuel sources for kilns, including the use of scrap wood and sawdust, tires, and other inefficient or highly polluting fuels;

- solicit the advice of experts from institutions of higher education, government, and industry of the United States and Mexico on efficient processes and fuels for maintaining proper temperatures for brick production while minimizing emissions of air pollutants;

- consider the information collected in the study and make recommendations on efficient processes to decrease air pollutant emissions from brick-making kilns; and

- not later than January 1, 2003, issue a report to the governor, lieutenant governor, and speaker of the House of Representatives that summarizes the information and conclusions of the study, and highlights recommendations.

The entire text of SB 749 can be found in Appendix 1.

Background on Air Quality in the Paso del Norte Region

Pollution along the border between the United States and Mexico is exacerbated by rapid industrialization and population growth along both sides of the border. These issues require binational efforts to attack the problem. Cooperation between the U.S. and Mexican governing bodies at the local, state, and federal levels plus public participation is required if environmental problems are to be addressed and perhaps abated in border communities. In the area where the three states of Texas, New Mexico, and Chihuahua come together–known as the Paso del Norte–an airshed is shared between the two nations and the three States.

As stated previously, under the 1990 Clean Air Act all or parts of El Paso County were designated as nonattainment for three of the six NAAQS. El Paso County is classified serious nonattainment for ozone (O_3), and the City of El Paso is in moderate nonattainment for particulate matter with an aerodynamic diameter of 10 micrometers or less (PM_{10}), and parts of the City of El Paso are in moderate nonattainment for carbon monoxide (CO).

Air quality trends for El Paso indicate the region could be redesignated as an area in attainment of carbon monoxide, ozone and particulate matter. The TCEQ is considering requesting from EPA redesignation for El Paso as an area in attainment of the NAAQS for carbon monoxide and ozone. At a more specific level, technical questions regarding ambient air quality data that have been reported will be examined by EPA prior to redesignation of El Paso. A Maintenance Plan–containing contingency measures that would be implemented should El Paso violate the NAAQS at some future date–would be included in the redesignation request.

It is beyond the scope of this study to examine El Paso's air quality issues in detail, but a more explicit discussion of El Paso air quality issues can be found in the TCEQ's *2002 State of the Rio Grande and the Environment of the Border Region*, pp. 63-71.[3]

Scope of Study

TCEQ staff met with legislative staff and members of the JAC to present the proposed method for undertaking the study required by SB 749. TCEQ officials presented the proposal to the JAC at the December 13, 2001, and April 24, 2002, meetings.

Based on input received, the TCEQ initiated the study by reviewing past and current research efforts regarding brick-making processes of brick production facilities near both sides of the border between Texas and Mexico, focusing on the Paso del Norte area. There were no brick manufacturers with emissions from the Texas side of the border in the El Paso area (Nettles, 2002a), nor anywhere else along the Texas border outside of El Paso (Nettles, 2002b). Using information obtained from this process, the TCEQ circulated a draft report among members of the JAC, which includes experts from institutions of higher education, government, and industry of the United States and Mexico. Based on comments the TCEQ obtained from the JAC, the draft report was revised and then printed for distribution to the governor, lieutenant governor, and speaker of the House of Representatives.

Report Organization

Chapter 1 of this report is the Executive Summary. Chapter 2 provides an introduction to air quality issues in the Paso del Norte airshed and provides background. Chapter 3 describes brick-making operations in Ciudad Juárez, including the general number and location of kilns in Ciudad Juárez, with a description of the brick-making industry. The typical brick kiln is also described, as well as brick-making procedures and time frames. In Chapter 4 the types of fuels used in brick kilns are

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[3]The El Paso air quality section can be found online at **http://www.tnrcc.state.tx.us/admin/topdoc/sfr/035_02/vol3_chap3.pdf** (TNRCC, 2002).

related, including data gathered from a recent survey, followed in Chapter 5 by characterization of emissions from brick kilns. Chapter 6 lists previous studies conducted in the brick kiln industry, with a brief summary of what was learned in those studies. Chapter 7 discusses participants in initiatives to improve emissions in the brick-making industry, and the final chapter contains conclusions and recommendations, followed by appendixes.

3. Brick-Making Operations in Ciudad Juárez, Chihuahua

In the area of air pollution, perhaps the most visible and easily addressed problem in Ciudad Juárez is the typical batch-style brick kiln. Batch-style brick-making operations have gone essentially unchanged for hundreds of years. From 6,000 to 30,000 bricks (depending on the dimensions of both the kiln and brick) are loaded into a kiln and fired using wood or other fuels to cure and harden the structural integrity of clay. Figures 2 and 3 in Appendix 6 show these kilns during the firing process. Centuries of operating essentially without modification and improvements have resulted in extremely inefficient industrial combustion processes.

A first step in improving the brick-making process is modifying the combustion process to reduce smoke emissions. This should be done through passive means (considered Appropriate Technology) since active mechanical devices will typically malfunction and not be replaced and/or maintained by the brick maker.

Number and Location of Brick Kilns in Ciudad Juárez

As of September 2002, there are at least 332 individual operating brick kilns in Ciudad Juárez located primarily in the south-central and southeast sections of the city. See Figure 1 in Appendix 6 for a map of the locations of the kilns. Sixteen independent groups of brick-making neighborhoods or *colonias* (Col.) are governed by a brick makers' syndicate, yet independent brick makers operate within these neighborhoods and are not required to become members of any syndicate. Table 1 provides a listing of the colonias in Juárez where the brick makers are located and the number of brick kilns located therein.

Table 1: Brick-Making Colonias of Ciudad Juárez	
Colonia Name	**No. of Brick Kilns**
Pablo Gomez	31
Ignacio Ramos	69
Francisco Villa	10
Libramiento Km 20	2
Garita Km. 30	2
Sector Km. 27	5
Granjas El Dorado	9
México 68	115
División Del Norte	6
Felipe Angeles	18
Fronteriza Baja	13
Satélite	39
Río Bravo	4
Emiliano Zapata	1
Waterfill	7
Andrés Figueroa	1
TOTAL	**332**

Source: Juárez, 2002

The brick-making colonias were established in regions of Ciudad Juárez that at the time were located quite some distance from populated urban regions of the city. However, due to the high growth rate experienced by Juárez during the past 40 years, residential and industrial growth soon surrounded the brick-making colonias. Some brick-making colonias are also located near ancient alluvial zones which contain the clay material used for brick fabrication. As the nearby raw materials dwindle, a small industry has developed to deliver clay and other supplies to the brick-makers. An added service industry is one which delivers sawdust, wood scraps, and any other allowable combustible material to the brick makers for the firing process.

Basic Information on the Brick-Making Industry

The Juárez brick-making industry is estimated to support approximately 2,100 brick makers and their families (FEMAP, 1994). The brick makers either own or rent the individual brick kilns. According to an agreement between the Mexican government and the union leaders, limited kiln operation has been implemented to reduce air pollution generated by this industry (PROFEPA, 1998). Approximately 20 to 40 brick kilns may be operating on any given day with the exception of Sunday, considered a day of rest. Information developed by the Ciudad Juárez Ecology Office and PROFEPA (Mexico’s Federal Attorney General for the Protection of the Environment) indicated Ciudad Juárez brick makers fire their ovens an average of 14 times per year (PROFEPA, 2002).

The Typical Brick Kiln: Description and Operating Procedures

A typical brick kiln in Ciudad Juárez (See Figures 2 and 3) consists of a cubic structure with approximate dimensions of three meters each in length, width, and height above grade.[4] Construction material of the kiln consists of adobe block with approximate dimensions of 40 centimeters (cm) by 30 cm by 10 cm. Approximately 3000 adobe blocks are required to construct a typical kiln. A sloping pit is dug approximately two meters deep and three meters in radius on one side of the kiln. Below grade of the cubic structure is the firing chamber. A hole approximately 0.35 meters in diameter is made at the base of the wall of the kiln about 25 cm from the bottom of the pit. The hole allows the kiln operator to supply combustible materials to fire the kiln. This is called the firing port.

Looking through the firing port, there are four to six separate arches running perpendicular to the observer. The arches are constructed of fired brick. The total height of the arch is about 1.8 meters, and the height of the inside arch is about 1.4 meters. The space at the inside base of the arch is some 1.5 meters. On the opposite side of the pit above grade is an opening into the kiln, called the kiln door, through which the operator loads the bricks. Special care is taken when stacking the bricks to provide sufficient spacing between bricks to allow the heat of the fire to penetrate to the uppermost section of the kiln during the firing process. Once the kiln is loaded, the kiln door is blocked with fired or unfired bricks and sealed with mud-mortar to prevent heat loss within the kiln and assure emissions exit from the top of the kiln. The kiln operator loads the combustible material through the firing port of the kiln at a rate generally not consistent among brick makers. However, an attempt is always made to maintain an active firing process to assure the temperature of the kiln reaches the minimum firing temperature of 600 degrees Celsius (ºC).

Throughout the 24- to 30-hour firing period, the laborer continuously feeds and periodically stokes the wood or other material (with a long-handled metal rake) to maintain a fire within the kiln.[5] Low technology firing methods often result in under- or over-fired bricks. Under-firing requires that the brick be refired since the brick remains covered by a layer of soot indicating sufficient firing temperatures were not reached. Over-firing ruins the brick, causing it to vitrify (become like glass) and

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[4]This chapter describing brick kilns and their operating procedures is adapted from Robert Marquez' doctoral dissertation (Marquez, 2001).

[5]Brick makers also monitor the process by walking along the perimeters of the top of the kiln, at great risk to their own health and safety.

become a less saleable product. The sporadic refueling results in localized starved air conditions (causing incomplete combustion) within the firing chamber producing thick black smoke emitted from the top of the roofless kiln.

Brick-Making Procedures and Time Frames

The Mexican brick makers use sand and clay materials in production of their bricks. Two distinct sizes of bricks are manufactured: the smaller *ladrillo* and the larger *tabique*. *Ladrillo* bricks have approximate dimensions of 30 cm by 15 cm by 5 cm. *Tabique* bricks have approximate dimensions of 30 cm by 15 cm by 10 cm. Each type of brick is regularly manufactured at all brick kilns. Given the type of material composition, extremely high temperatures (600ºC or higher) are required to bond these material components together. For proper firing, all bricks need to be maintained at a constant temperature of about 600ºC for a minimum period of one hour (Marquez, 2001). Brick makers operate their kilns less and produce fewer bricks in the winter months because of the lack of ambient sun drying capabilities as well as seasonal slowdown of the construction industry (Vásquez, 2000). Table 2 shows the individual steps with estimated time frames required to produce one batch (10,000 units) of fired bricks.

Table 2: Individual Steps Required to Make Bricks	
Step in Brick-Making Process	**Time (Hours)**
Mixing of sand and clay ingredients with about 20-30% water	6 to 10 hrs
Performing pressing/molding hand operations	12 to 24 hrs
Ambient air sun drying (90ºF days)	24 to 48 hrs
Placement of sun dried bricks in kiln	12 to 15 hrs
Start kiln fire (wood fuel)	0 hrs
Majority of brick moisture is diffused	2 to 4 hrs
Kiln obtains desired operating temperatures	4 to 8 hrs
Operators start to monitor kiln temperatures	8 to 12 hrs
Operators monitor and direct draft flows/heat	12 to 24 hrs
Broken bricks are placed on top layer of bricks Sawdust/shavings/pallets are placed on top of broken bricks and set afire to complete baking process of top layers	2 to 4 hrs
Total kiln brick baking process time	20 to 30 hrs
Kiln cool-down	12 to 24 hrs
Removal of baked bricks from kiln	12 to 15 hrs
Load bricks onto truck for distribution	2 to 4 hrs

Source: MRI, 1997

A typical cycle for a batch process, from mixing of the clay materials to removal of the fired bricks for distribution, may require an entire week. Most brick kiln operators report that to produce a known quantity of bricks requires the following amounts of wood and/or sawdust (MRI, 1997):

6,000 bricks - 3 tons wood/sawdust
10,000 bricks - 4 tons wood/sawdust
15,000 bricks - 5 tons wood/sawdust
25,000 bricks - 6 tons wood/sawdust

4. Fuels Used in Brick Kilns

The fuel used for the kilns is usually whatever is cheap and readily available. In Juárez this consists primarily of sawdust, wood shavings, and scrap wood. The wood materials may contain resins and chemicals used in the manufacture of television consoles and furniture. In an annual survey of brick makers, of 111 responses, the following fuels were found to have been used (PROFEPA, 2002):

Sawdust only -	91 kilns, or 82 percent
Wood only -	11 kilns, or 10 percent
Sawdust and wood -	9 kilns, or 8 percent

Brick makers also use other fuels e.g., tires, used motor oil, plastics, and garbage; however, this practice has been discouraged by the Mexican federal government through a formal agreement developed between PROFEPA and the brick makers to use only clean sawdust, wood shavings, and scrap wood for firing kilns (PROFEPA, 1996). Propane fuel (LP gas) was used by a number of the kilns between 1994-1996 until LP gas prices increased substantially and most of the brick makers returned to the more affordable wood fuels (Blackman, 1998).

In other areas, such as Saltillo, Coahuila, a survey found that 55 percent of the fuel used in open kilns was scrap tires, with the remainder being mostly wood (COMIMSA, 2001).

5. Emissions Produced by Brick Kilns

The most important reason for researching brick kilns is to reduce air pollution emissions. Given the fuel source used and the combustion efficiencies obtained by a typical brick kiln, an evaluation of the emissions must be undertaken. Emissions tests usually include measurements of carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter (PM_{10}), and volatile organic compounds (VOC). Following emissions testing to determine pollutants from a typical unmodified brick kiln, a second step is to modify the kilns to reduce emissions and determine the extent of emissions reductions. While an estimation of the health impacts associated with breathing emissions from the brick kilns is not within the scope of this paper, it should be noted that various papers have been developed which discuss the probable health impacts due to brick kiln emissions (Blackman, 1996, 1999, 2000).

Perhaps the most complete emissions tests of typical Ciudad Juárez brick kilns was conducted by El Paso Electric Co. (EPE, 2002). EPE retained URS Corporation to conduct emissions tests of a typical kiln at a site in Sunland Park, New Mexico. Testing was conducted in two phases, with the first phase consisting of measuring uncontrolled emissions from a typical kiln and the second phase consisting of implementing design modifications similar to those developed by New Mexico State University (NMSU) and measuring the resultant emissions in order to determine emission reductions from the modified kiln.

Emissions testing was performed for various components, including criteria pollutants as well as specific chemical compounds. Criteria pollutants measured included oxides of nitrogen (NO_x) and CO, as well as total particulate matter (TPM), polycyclic aromatic hydrocarbons (PAHs), VOCs, and sulfur dioxide (SO_2). Also, samples of the smoke plume were collected from most test firings and analyzed for particle size distribution. EPE conducted seven total test firings. PAHs, such as benzo-a-pyrene (also found in cigarette smoke), fluoranthene, and chrysene, are often associated with combustion of wood products.

EPE conducted four tests of emissions from the unmodified kiln and three tests of the modified kiln to obtain sufficient measurements to provide a degree of statistical significance to the emissions values reported. Table 3 identifies some of the emissions from unmodified and modified brick kilns.

TABLE 3: Emissions for Unmodified and Modified Kilns*†				
Kiln Type / Pollutant Type	**Unmodified Kiln Burns 2-4** Average of Results, lbs	**Modified Kiln (Marquez Kiln) Burns 6-7** Average of Results, lbs	**Reduction in Pollutant Type, lbs**	**Approx. Percent Reduction in Pollutant Type**
NO_x (as NO_2)	10.5	3.82	6.64	63
CO	617	334	283	46
Particulate (TPM)	98.9	16.6	82.3	83
VOCs	136	42.4	93.8	69
Total pollutants (lbs/Burn)	863	397	**466****	

* Results from Burns 1 and 5 were not included; in Burn 1, the new kiln was being seasoned and there were difficulties with the sampling system, and it was similar situation in Burn 5 for the modified kiln.

† Differences may not be exact due to rounding.

**Pounds of Pollutants Reduced per burn with modified kiln.

Source: EPE, 2002

A typical kiln generates about 863 lbs of pollutants per burn which are emitted into the Paso del Norte airshed. Given an average of 14 firings per kiln per year (firings/kiln-year) this adds up to about 12,082 lbs of pollutants per year per kiln (about 12,082 lbs/kiln-year). Assuming each of the 332 kilns operate in similar fashion throughout the year, total annual emissions from the kilns adds up to about 4,011,000 lbs (about 2,005 tons) of pollutants from the brick-making industry. Because of the variation in the types of fuel used by the brick makers in Mexico the amount of reductions quantified by EPE are conservative. The pollution quantified is conservative because it is based on emissions from the combustion of only wood pellets used as fuel.

Modified kilns generate about 397 lbs/burn of pollutants, or 54 percent fewer emissions than a traditional kiln. Of note is the very high reduction of PM, by about 83 percent. Such reductions in PM emissions may also help improve the respiratory health of the brick makers and their families and other residents. One other benefit associated with the modified kiln is the reduction in fuel consumption. A modified kiln uses 53 percent less wood. These reductions will translate into an improved operating margin for the brick maker and perhaps improve his standard of living due to the reductions in operating costs.

6. Previous Studies Conducted in the Brick Kiln Industry

Several in-depth environmental studies have been conducted on the brick kiln industry, and a few are listed here:

1. The process used to fire the bricks was studied by the Los Alamos National Laboratory (LANL) March 17-21, 1994. The evaluation included both monitoring of the internal kiln temperatures, as well as the effects of the application of hydraulic pressure to brick forming before firing the bricks. The results of the study showed that a wide temperature disparity existed within the kiln during the firing period. Researches determined that the kiln designs must be improved to minimize the temperature variations. Uniformly distributed temperatures within the kiln should improve the quality of the bricks fired at the outermost regions of the kiln, while minimizing vitrification of the bricks fired nearest the flames. This is difficult to accomplish and requires a very skilled operator for a traditional kiln (LANL, 1994).

2. Preliminary studies to analyze emissions from several brick kilns were conducted for El Paso Natural Gas Environmental Affairs. The results indicated that depending upon the type of fuel being used for firing, the smoke is filled with various types of pollutants, with carbon monoxide being the worst and most common compound.(Van, 1993).

3. A technical report was prepared by the El Paso Community Foundation for EPA on construction and development of the prototype cylindrical and Marquez kilns. The report provided temperature profiles over time as well as emissions data from firing the kiln using sawdust as well as propane gas (Valenzuela, 1997).

4. A thesis titled "*Aryl hydrocarbon receptor mediated effects of particulate organic extracts from the Paso del Norte airshed along the U.S.-Mexico border*" reported the sorption of soot compounds into a specific aquatic species to determine the level of bioaccumulation of organic emissions from the brick kilns (Arrieta, 2000).

5. A thesis titled "*Characterization and Reduction of Air Pollutants From Brick Kilns in Northern Mexico*" was prepared in 1997 by Eric S. Stewart, a University of Utah graduate student in Chemical and Fuels Engineering (Stewart, 1997).

6. In 1999 the Southwest Center for Environmental Research and Policy (SCERP) published a final report titled "*A Sustainable Solution to the Air Pollution Problem Caused by Low Technology Brick Kilns*" by Avila, *et al*, from NMSU and the Universidad Autónoma de Ciudad Juárez on the comparison of performance characteristics from open top conventional kilns vs. covered (MK type) kilns (Avila, 1999).

7. A 2001 dissertation by Robert O. Marquez of NMSU on "Appropriate Chemistry for the Economically Limited People of the Earth" was submitted as part of his work on a Ph.D. This dissertation is on Ciudad Juárez brick makers, the properties of their brick mix, clays, the characterization of brick kiln emissions, PAHs, and brick kiln design with a constant emphasis on improving the brick-makers' communities with the appropriate solution to a particular problem (Marquez, 2001).

8. A technical report titled "*Aerosol Characterization of Wood-Fed Brick Kiln Effluents in Ciudad Juárez, Chihuahua*" was prepared by Dr. C. W. Bruce, a physicist from NMSU. This report provided the most thorough reporting to date of particle densities emitted by brick kilns using nephelometry. Nephelometry is an estimate of scatter caused by particles in ambient air (Bruce, 1999).

9. A Discussion Paper prepared by Allen Blackman *et al* from Resources for the Future (RFF) titled "*The Benefits and Costs of Informal Sector Pollution Control: Mexican Brick Kilns*" developed several models such as an air dispersion model, a health effects model, and a valuation model to determine the health costs associated with exposure to brick kiln emissions (Blackman, 1999). Blackman has also co-authored several other papers available online at **www.rff.org**.

10. A previously cited 1998 journal article by Allen Blackman of RFF and Geoffrey J. Bannister of the University of New Mexico discusses the use by brick makers of propane for fuel. This report determines that the use of propane fuel by the brick makers did not achieve the expected benefits given that fuel costs were too high and usage was limited (Blackman, 1998).

11. A 2001 study by Mexico's Corporation for Materials Research (COMIMSA), "*Adecuación Tecnológica a Ladrilleras de Saltillo, Coahuila*," (Technological Adaptation for Brick Kilns in Saltillo, Coahuila) provided some valuable information about fuels used in Saltillo's 1,224 kilns, as well as about emissions from those kilns. To produce the famous "Saltillo" tile, in one month in 2000, 55 percent of the total fuel by weight in all of Saltillo's kilns—some 8,382

tons—was scrap tires, with most of the rest being wood. A study conducted measuring emissions using used tires as a fuel source provided the following results per burn: 118 lbs of total suspended particles; 118 lbs of NO_x; 79 lbs of sulfur dioxide (SO_2); and 1,426 lbs of CO. The emissions testing methodology cannot be considered comparable to methodology used by EPE. It should also be noted that Saltillo's elevation is 5,200 feet (ft) above sea level, whereas Ciudad Juárez is about 3,400 ft above sea level.

7. Participants in Initiatives to Improve Emissions in the Brick-Making Industry

Several years ago, the problems of the brick makers came to the attention of a Juárez nonprofit health and social service organization known as the Federación Mexicana de Asociaciones Privadas de Salud y Desarrollo Comunitario, or Mexican Federation of Private Associations of Health and Community Development (FEMAP). FEMAP developed the brick maker project. The project addressed the environmental hazards of the kiln firing process, the brick maker's working conditions, and living conditions. An educational facility named the Instituto de Ecotecnología (ECOTEC) was established by FEMAP to train and educate brick makers in the technical aspects of brick making. At ECOTEC brick makers learn the principles of energy conservation, kiln design, efficient kiln operation, and the environmental effects of polluting fuels. As ECOTEC developed, organizations such as LANL, University of Utah, El Paso Natural Gas, and SCERP contributed technical skills to the brick-making community of Ciudad Juárez.

In 1995, a $32,000 EPA Resource Conservation and Recovery Act (RCRA) grant to the El Paso Community Foundation funded construction of 14 brick kilns throughout Ciudad Juárez. This project became the basis for future improvements to the typical brick kiln. Following up on observations from LANL on the brick-firing process, which indicated the combustion process and structural integrity of the kiln required improvement, an effort was made by Mr. Horacio González Castillo, an environmental scientist, to modify the kiln design into a cylinder based on two premises.

First, the cylindrical kiln has greater structural integrity than a cube-shaped kiln. The second premise is that combustion efficiency improves, heat is better distributed within the kiln, and heat loss is reduced. The cylinder was designed to use propane burners which could be positioned strategically to try to create a vortex and improve the hot gas flows throughout stacked bricks and improve heat transfer. Since the gas conversion project terminated, the cylindrical kiln design was converted to the wood and wood product combustion design that was similar to that of the conventional cubic kilns.

The first cylindrical kiln was constructed at the ECOTEC. Mr. González conducted several emissions tests in coordination with the ECOTEC, which provided thermocouples supplied by LANL, and EPNG, which provided gas sampling equipment and technicians. The cylindrical kiln was an improvement over the traditional cubic kiln. Cube-shaped kilns develop broken and cracked corners in the kiln walls caused by stress concentration points. The stress originated by the operating conditions within the kiln where temperatures can reach ~1200ºC within the firing chamber and over 600ºC among the stacked bricks. Early tests indicated the cylinder had modestly lower emissions than a cube-shaped kiln, although reductions were not substantial.

The second modification of the kiln funded through this same grant was installation of both a functional plenum roof over the cylindrical kiln and a clay filtration system with chimneys (the plenum is a shaft attached to the top of the kiln which re-directs emissions in a horizontal direction). Mr. Robert Marquez, at the time an NMSU Doctoral Candidate, proposed this concept (Marquez Kiln), and to date continues to construct updated versions of this kiln design. See Figure 4, Appendix 6. The first update of the design was to make the system practical and appropriate by making the plenum and roof with adobe bricks configured into a dome shape, making the chimneys out of fired bricks, and making the clay filtration system out of raw unfired bricks. Subsequent design updates were to optimize kiln system performance.

The Marquez Kiln (MK) design has three premises that will improve brick kiln performance and reduce emissions. The first premise is that combustion efficiency is improved by minimizing heat and energy loss. This is accomplished by having a domed adobe roof and heat recapture system. The second premise is that combustion efficiency is improved by better mixing of air with the fuel. This is accomplished by controlling the firing port size, plenum exit port size, and the chimney stack dimensions (height and effective inner diameter or area). The third premise is that the new system will be readily accepted by the brick makers because it significantly reduces fuel consumption and utilizes the same materials and construction techniques with which the brick maker is already familiar.

Placing a cover over a traditional kiln appears to be the greatest obstacle in modifying the brick kilns. Two reasons that make this difficult are; moisture and kiln temperature monitoring. First, bricks contain roughly 10-15 percent moisture content after drying in the sun. While a brick may appear dry after being sun dried, water molecules are trapped within the matrix of the clay structure of the brick, and this moisture is difficult to extract. The early stages of the firing process involve extraction of this water as steam, which may condense and fall on the top layer of bricks thereby ruining them. Extraction of all water is imperative in order to achieve the temperatures required to chemically change the clay minerals and harden the brick. An estimate of moisture content indicates that if a sun-dried brick weighing one kilogram (kg) is 10 percent moisture, then

100 grams (g) of the brick weight is water. Assuming the kiln holds 10,000 bricks, then 1000 kg of water needs to be removed before the bricks can heat up to a temperature where a chemical reaction within the alumina-silica matrix of the clay hardens the brick into a usable product.

Virtually all brick makers climb on top of their traditional kilns to seal them off after the moisture has been removed from the bricks. This potentially exposes them to hazardous working conditions such as intense heat and toxic gases (for example, CO, VOCs, and PAHs). By including a plenum section in a permanent roof design with an exit port at the bottom of the plenum, steam can be extracted through the bottom of the plenum section and cannot condense on the roof of the kiln. This permanent roof eliminates the hazards of working on top of a fired kiln. Climbing on top of a traditional kiln also allows the brick maker to monitor the firing of the kiln and know when the kiln firing is complete. In a permanent roof kiln, temperature measurement and/or monitoring must be incorporated in the design. In an MK type-kiln this is accomplished with a temperature measurement device.

A temperature measurement device in an MK kiln allows the kiln operator to visually determine when a kiln firing is complete. Near the top of the stacked bricks within the kiln and just below the domed roof enclosure (in the plenum section), a steel pipe with dimensions 2.5 feet long and four-inch diameter is inserted diagonally. One half of the pipe is within the kiln and the other half is outside; the lower end of the pipe is on the inside and is plugged with mud, the upper end is outside the kiln and is open. Into the open end of the pipe one installs several empty aluminum cans. At 660ºC, aluminum melts causing the cans to disappear into the pipe. Once the aluminum cans melt, the operator knows that the optimum firing temperature has been achieved within the kiln and he can cease adding fuel to the firing chamber.[6]

Subsequent modifications of the MK attach two kilns constructed approximately three meters apart via an underground channel. The concept is such that once the firing process is maintained and a certain emissions flow rate is achieved through the stack of the primary kiln, the stack is capped forcing the hot emissions through the underground channel. The hot gaseous emissions then enter the second kiln where the soot and smoke is adsorbed onto the fresh unfired bricks. At the second kiln, the hot gases first drive the moisture off of the raw unfired bricks and the soot and other toxic compounds (metals) bind to the bricks.

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[6]A second, more expensive option is to construct thermocouples and use a voltmeter to measure temperature. This approach can cost between $40 and $100 (Avila, 1999).

As the film layers of soot become larger, more VOCs partition into the organic phase (soot) and are also bound to the raw bricks. When a sooted brick in the second kiln is broken in two halves, soot is observed to have penetrated to the center of the solid brick. Smoke emissions are again substantially decreased by filtration through the second kiln. When firing of the primary kiln is completed, the bricks are removed and fresh bricks are stacked within it. The second kiln becomes the primary kiln and the process is reversed, forcing smoke into what was originally the primary kiln.

Another interesting aspect of this alternating method of firing bricks and filtering the smoke through the second kiln is that the properties of the hydrocarbons sorbed into and onto the bricks act as an attached fuel. They are converted to carbon dioxide and water when combusted properly during the reversed second firing. This helps reduce the amount of fuel required to burn on the second and subsequent firings. The amount of wood fuel consumed is reduced by about 50 percent (URS, 2002). The second kiln also acts as a protected storage for raw unfired bricks and is the energy storage device (heat recapture system) for the brick kiln system that filters out toxic pollutants as well. This storage capacity saves space for the brick maker, and outside stacking space for unfired brick is not needed; i.e., stacking space outside is saved because the bricks can now be stacked inside the second kiln. Preliminary data gathered from the brick-making communities suggest that these systems may become "the norm" of the future due to all of the operational and financial benefits.

Groups Currently Undertaking Brick Kiln Research

There are three groups involved in researching emissions from brick kilns and modifying kiln designs. The three groups include EPE and two consortiums listed below.

As previously discussed, EPE is one group that has conducted studies of brick kiln emissions. EPE is seeking, under requirements established under SB 7, 76th Legislature, to reduce NO_x emissions at its grandfathered electrical generating facilities in El Paso County. Under SB 1561, 77th Legislature, utilities in El Paso County are allowed to use emission reductions of criteria pollutants achieved at facilities outside the U.S. to satisfy requirements for reductions in another criteria pollutant in Texas, provided certain conditions are met. The TCEQ has adopted rules to implement SB 1561.[7] EPE examined brick kilns as one source for the emissions substitution. With this in mind, EPE recently tested emissions from traditional kilns and the MK kiln configuration at its Brick Kiln Proving Grounds located in Sunland Park, New Mexico.

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[7] 30 TAC. *Texas Administrative Code*. Chapter 101, Subchapter H.

EPE obtained required permits from the New Mexico Environment Department (NMED) for operation of an open burning facility and contracted with URS Corporation with the purpose of developing a method for measuring emissions from both the open kiln and the MK. Figure 5, Appendix 6, shows emissions from the Marquez Kiln. The TCEQ approved the emissions testing methodologies in 2002. The values obtained allowed EPE and TCEQ to determine the amount of reductions that could be used to create allowances for the Emissions Banking and Trading of Allowances (EBTA) Program per kiln constructed in Ciudad Juárez. EPE made formal application for an international trade in August and TCEQ approved the request on November 16, 2002. EPE's goal is to complete the construction of 60 Marquez kilns by May 2003.

A second group researching emissions reductions from brick kilns is a consortium between ECOTEC, the University of Texas at El Paso (UTEP), the Centro de Investigación en Materia Avanzada (CIMAV), the Universidad Autónoma de Ciudad Juárez (UACJ), the Ciudad Juárez Ecology Department, and Environmental Defense. CIMAV provides graduate and post-graduate instruction in Chihuahua City. The ECOTEC brick-makers group has begun testing emissions from a single Environmental Brick Kiln (EBK) with a domed roof and plenum-stack configuration.

A third group researching emissions from brick kilns is a consortium that includes NMSU, UACJ, the Border Technology Partnerships Program (BTP) of the U.S. Department of Energy, and Applied Sciences Laboratory, Inc. This consortium has furthered the research on the MK design. Current modifications involve connecting multiple kilns through a series of underground conduits in order to channel the kiln emissions to any selected kiln for adsorption.

8. Conclusions and Recommendations

Efforts to reduce air pollution from the Ciudad Juárez brick kilns initially began in the early 1990s. Three groups have been researching methods of constructing brick kilns to make them more efficient by improving the combustion process and reducing fuel requirements. By modifying the kiln design and improving efficiency, an 82 percent reduction in particulate emissions has been achieved, and an overall reduction in emissions of 54 percent.

Following are the primary recommendations from this study on efficient processes to decrease air pollutant emissions from brick-making kilns along the border between Texas and Mexico.

- **The principal recommendation is to continue to encourage and support the implementation of the new kiln technology in Ciudad Juárez**, using either the Marquez Kiln or the Environmental Brick Kiln. Both of these kiln designs accomplish improvements in fuel consumption for all brick making of this nature taking place in Mexico. In addition, the designs of the Marquez Kiln and data from testing of this kiln show a vast improvement over the current cube-shaped design, which emits great amounts of particulate matter, carbon monoxide, and other pollutants. Also, the benefits of using improved combustion sources made of native construction materials with construction processes known to the brick makers will allow for a much easier transition to the new kiln designs.

- **We do not recommend using cleaner-burning fuels as the most cost-effective means of reducing brick kiln emissions.** Fuels, such as natural gas or propane or liquified petroleum gas (LP gas) potentially could help reduce emissions. However, experience with these fuels shows that they are a less effective way to reduce emissions than other approaches. The main deterrent is the elevated cost that generally prices these fuels out of the reach of brick makers (Blackman, 1998). Improved combustion efficiency with cheap fuels is the most practical solution to reduced emissions.

- **We recommend the continued discouragement of the use of such fuels as used oils and scrap tires, which may not fully combust in the brick kiln.** This is the current position of the JAC and the various levels of Mexican government.

Appendixes

Appendix 1

Senate Bill 749

AN ACT

relating to the authority of the Texas Natural Resource Conservation Commission to participate in environmental projects in Mexico and to study means to reduce air pollutants in certain facilities in the border region.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF TEXAS:

SECTION 1. Subchapter D, Chapter 5, Water Code, is amended by adding Section 5.127 to read as follows:

Sec. 5.127. ACTIONS IN MEXICO. The commission may take and finance any action in Mexico, in cooperation with governmental authorities of Mexico, that in the opinion of the commission:

(1) is necessary or convenient to accomplish a duty of the commission imposed by law; and

(2) will yield benefits to the environment in this state.

SECTION 2. BRICK-MAKING PROCESSES STUDY. (a) The Texas Natural Resource Conservation Commission, in cooperation with the Joint Advisory Committee for Improvement of Air Quality, shall conduct a study of the brick-making processes of brick production facilities near both sides of the border between this state and Mexico.

(b) The Texas Natural Resource Conservation Commission shall survey current fuel sources for kilns, including the use of scrap wood and sawdust, tires, and other inefficient or highly polluting fuels.

(c) In conducting the study, the Texas Natural Resource Conservation Commission shall solicit the advice of experts from institutions of higher education, government, and industry of the United States and Mexico on efficient processes and fuels for maintaining proper temperatures for brick production while minimizing emissions of air pollutants.

(d) The Texas Natural Resource Conservation Commission shall consider the information collected in the study and make recommendations on efficient processes to decrease air pollutant emissions from brick-making kilns.

(e) The Texas Natural Resource Conservation Commission shall issue a report to the governor, lieutenant governor, and speaker of the house of representatives that summarizes the information gathered in and conclusions of the study and that highlights the recommendations. The report must be issued not later than January 1, 2003.

(f) This section expires January 1, 2003.

SECTION 3. This Act takes effect immediately if it receives a vote of two-thirds of all the members elected to each house, as provided by Section 39, Article III, Texas Constitution. If this Act does not receive the vote necessary for immediate effect, this Act takes effect September 1, 2001.

S.B. No. 749

____________________________________ ____________________________________
President of the Senate Speaker of the House

I hereby certify that S.B. No. 749 passed the Senate on April 18, 2001, by the following vote: Yeas 29, Nays 1, one present not voting; and that the Senate concurred in House amendment on May 27, 2001, by a viva-voce vote.

____
Secretary of the Senate

I hereby certify that S.B. No. 749 passed the House, with amendment, on May 23, 2001, by the following vote: Yeas 136, Nays 0, one present not voting.

____
Chief Clerk of the House

Approved:

____
Date

____
Governor

Appendix 2

Endnotes

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Appendix 3

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Appendix 4

List of Acronyms

CIMAV	*Centro de Investigación en Materia Avanzada* (Center for Advanced Materials Research)
cm	Centimeter (one hundredth of a meter, or about 0.4 inches)
CO	Carbon monoxide
COMIMSA	*Corporación Mexicana de Investigación de Materiales, S.A.* (Mexican Corporation for Materials Research)
EBK	Environmental Brick Kiln
ECOTEC	*Instituto de Ecotecnología* (Institute of Ecotechnology)
EI	Emissions inventory
EPA	U.S. Environmental Protection Agency
EPE	El Paso Electric Company
EPNG	El Paso Natural Gas
FCAA	U.S. Federal Clean Air Act
FEMAP	*Federación Mexicana de Asociaciones Privadas de Salud y Desarrollo Comunitario* (Mexican Federation of Private Health and Community Development Associations)
ft	Foot or feet (English unit of measurement)
g	Grams
JAC	Joint Air Quality Advisory Committee for the Improvement of Air Quality in the El Paso, Texas/Ciudad Juárez, Chihuahua/ Doña Ana County, New Mexico Air Basin
kg	Kilograms
LANL	Los Alamos National Laboratory, U.S. Department of Energy
LP	Liquified petroleum gas

MK	Marquez Kiln
NAAQS	U.S. National Ambient Air Quality Standards
NMED	New Mexico Environment Department
NMSU	New Mexico State University
NO_x	Oxides of nitrogen
O_3	Ozone
PAHs	Polycyclic aromatic hydrocarbons
$PM_{2.5}$	Particulate matter smaller than 2.5 micrometers in diameter, sometimes called "fine" particulate matter
PM_{10}	Particulate matter smaller than 10 micrometers in diameter
PROFEPA	*Procuraduría Federal de Protección al Ambiente* (Federal Attorney General for the Environment, Mexico's Federal environmental enforcement agency)
RCRA	U.S. Resource Conservation and Recovery Act
SCERP	Southwest Center for Research and Policy
SEDESOL	Mexico's Federal *Secretaría de Desarrollo Social* (Secretariat for Social Development)
SO_x	Oxides of sulfur
TCEQ	Texas Commission on Environmental Quality
TNRCC	Texas Natural Resource Conservation Commission
TPM	Total particulate matter
UACJ	*Universidad Autónoma de Ciudad Juárez* (Ciudad Juárez Autonomous University)
UTEP	University of Texas at El Paso
VOCs	Volatile organic compounds

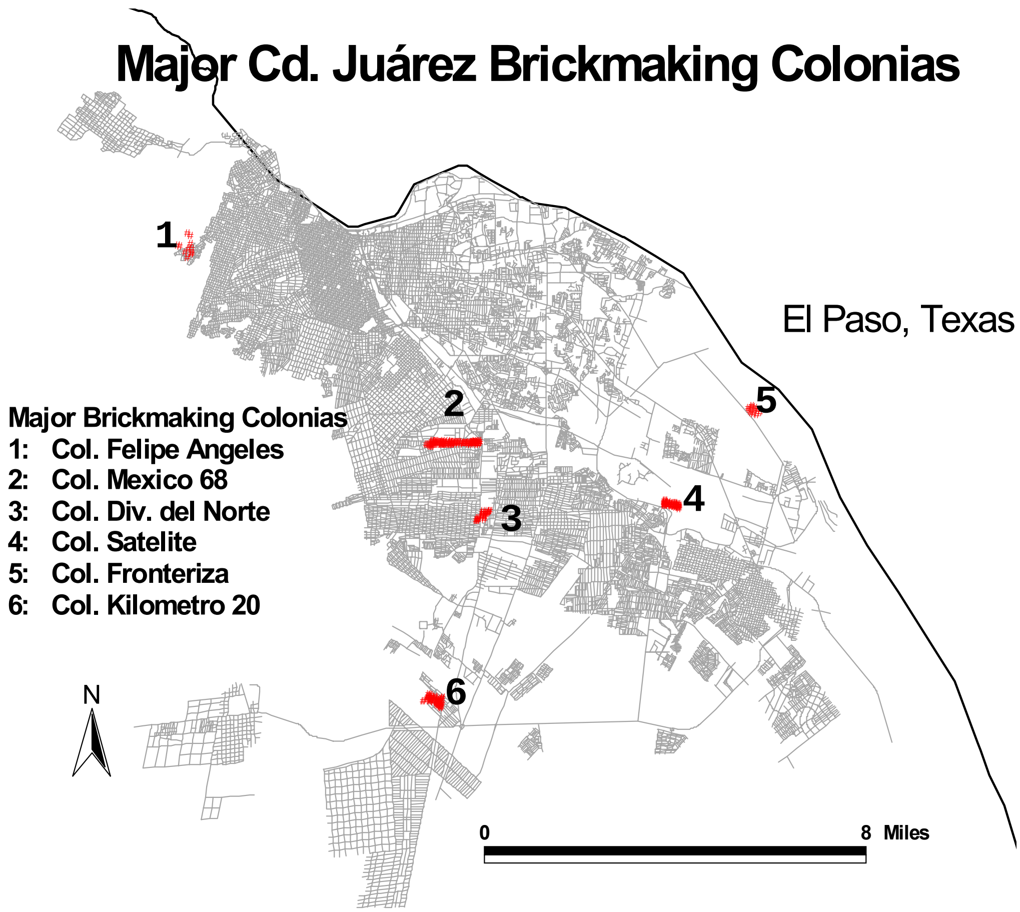
Appendix 5

Glossary of Terms

Appropriate Technology	Technology that is connected to the place, resources, economics, culture and impacts of its uses (see **www.dcat.net**)
carbon monoxide (CO)	A product of burning fossil fuels that impedes the blood's ability to deliver oxygen.
criteria pollutants	The six pollutants that the EPA, as required under the FCAA, determined to be the most dangerous to public health and welfare: ozone, nitrogen dioxide, sulfur dioxide, particulate matter, carbon monoxide, and lead.
emissions inventory	A listing, by source, of the amounts of pollutants actually or potentially discharged. Such an inventory is used to establish and put forth emission standards.
La Paz Agreement	Agreement signed in 1983 between the United States and Mexico and known formally as the Agreement on Cooperation for the Protection and Improvement of the Environment in the Border Area. Defines the border region as extending 100 km. (62.5 miles) on either side of the U.S.-Mexico boundary.
municipio	The level of Mexican government that corresponds to a U.S. county.
nonattainment area	A geographical area within the U.S. not in compliance with the National Ambient Air Quality Standards.
oxides of nitrogen (NO_x)	Products of combustion by mobile and stationary sources and a major contributor to the formation of harmful ozone.
ozone (O_3)	In the lower atmosphere ozone is a major component of photochemical smog and is formed through a chemical reaction between volatile organic compounds and nitrogen oxides in the presence of heat and sunlight.
particulate matter (PM)	Very fine solid or liquid particles in the air or in an emission. Particulate matter includes dust, smoke, fumes, mist, spray, and fog.
volatile organic compounds (VOCs)	Carbon-containing precursor compounds that undergo chemical reactions in sunlight and help create smog.

Appendix 6–Figures

Figure 1: Major Ciudad Juárez Brick-Making Colonias



Source: Valenzuela, 1997.

Figure 2: Unmodified Brick Kiln

Source: Victor Valenzuela

Figure 3: Final Firing Stage of an Unmodified Brick Kiln

Source: Victor Valenzuela

Figure 4: Marquez Kiln

Source: El Paso Electric Corporation

Figure 5: Marquez Kiln during Burn

Source: El Paso Electric Corporation