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An Environmental and Public Health Analysis of Possible Alternative Energy Resources for Indiana

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Abstract

This paper examines the environmental health effects of three alternative energy technologies being considered by the state of Indiana; waste coal combustion, coal gasification, and tire incineration. In particular, this study focuses on the toxic air emissions of these energy technologies. This study also considers the environmental health effects of surface coal mining; the most common process by which Indiana extracts coal. Through an exhaustive literature review of the environmental and public health effects of each supplemented with direct contact of professionals, academics, government and non-profit agencies, and research bodies, this study concludes that there is a severe deficit of peer-reviewed literature and scientific research on the public health effects and emission profiles of these technologies. Emissions and environmental profiles found through this analysis suggest potential links between these energy technologies and public health concerns, but due to a lack of scientific research and peer-reviewed literature on the subject matter, no clear causational link could be established.

An Environmental and Public Health Analysis of Possible Renewable Energy Resources for Indiana

Background & Introduction

Coal is widely used for electric power generation in the United States, accounting for almost half of the electricity generation nationally (Bergerson, 2007). Indiana is one of the most coal dependent states in the country, relying on coal for approximately 94.5% of its energy needs. The use of coal for energy production has vast public health ramifications, ranging from the soil and water contamination resulting from mining coal to the toxic air emissions released by coal combustion. Indiana currently ranks among the top five states in the nation in terms of its per capita mercury, NO_X, SO_X and toxic air emissions from its power and manufacturing plants (U.S. Energy Information Administration (EIA), 2006). Despite well documented emission profiles of energy generated from traditional pulverized coal technology, coal continues to provide the vast majority of Indiana's electricity, producing approximately 122,817 gigawatt/hours of electricity per year for the state (EIA, 2006). A 2007 report by the Indiana Center for Coal Technology Research projects that, in the next 17 years, the demand for electricity will increase by 49.5% (Irwin, 2007). These indicators have serious impacts on Indiana's public health, leading to billions in avoidable health expenditures, and dozens of premature deaths per year.

To address the increasing demand for energy in Indiana, this paper will evaluate the environmental health impacts of potential alternative energy sources currently being considered in Indiana. This paper will examine the toxic air emissions and potential public health effects of waste coal combustion, coal gasification, and tire incineration, while also taking into consideration the effects of surface mining as the process for coal extraction. These technologies were chosen as the focus of this study by the research preceptors at the Hoosier Environmental Council (HEC). Additionally, recent legislative activity in Indiana has considered proposed bills that would provide financial incentives for these alternative energy technologies, however these discussions have not included consideration of the public health implications of these technologies. Based upon the findings of this research, this paper concludes with recommendations regarding the aforementioned alternative energy sources in terms of their place in the future of Indiana electricity production.

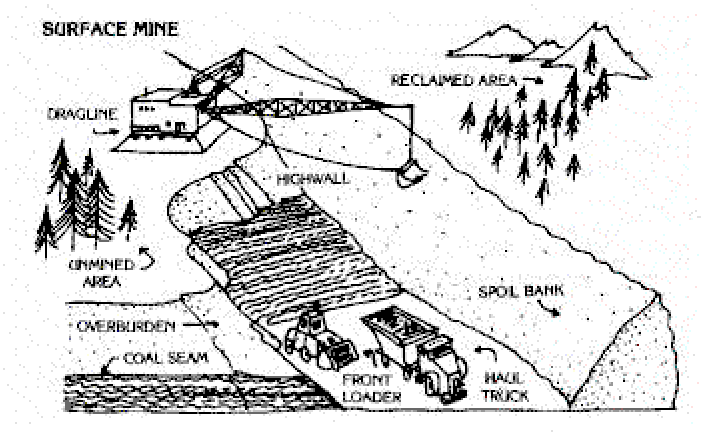
Literature Review

a. Strip Mining

Beginning in the 1930s, strip mining, also known as surface mining, became the most common form of coal mining in Indiana (Indiana Geological Survey (IGS), 1998). In fact, the IGS (1998) reports that more than 160,500 acres have been disturbed by surface mining for coal in Indiana. This mining has been limited to 21 counties in southwestern Indiana, and is mostly present in Clay, Greene, Pike, Sullivan, Vigo and Warrick counties. The technique of strip mining involves excavating large rectangular pits, which are developed in a series of parallel strips (Squillace, 1990). The depth of a coal seam dictates the types of equipment needed to remove the overburden above the seam. As technology has advanced from steam power to diesel, and now to electrically powered machinery, the size of equipment used and the equipment’s capabilities have greatly advanced. Whereas it was unusual twenty-five years ago to surface mine coal at depths greater than sixty feet, equipment today is capable of removing 200 cubic yards of overburden at a time such that coal seams approaching 200 feet in depth are considered mineable (IGS, 1998). Indiana contains bituminous coal, which contains very little moisture and has a high heat value. Bituminous coal is widely used to generate electricity and to make coke used in the steel industry (Indiana Department of Natural Resources, n.d.). In 1999, 34.9 million tons of bituminous coal was mined in Indiana.

Most surface mines follow the same basic steps to extract coal. The first step entails the scalping, or removal, of all overlying vegetation, soil, and underground layers of rock in order to expose and extract coal from an underground seam, or coal deposit. This removal is done through the use of bulldozers, scrapers, or loaders (Squillace, 1990). The exposed overburden, or the remaining sub-soil and rocks overlying the coal seam, is then drilled and blasted, and removed with tools such as bulldozers and power shovels. This step also includes the use of explosives, which shatter the rock in the overburden. Power shovels or draglines then clear away the overburden until the coal is exposed, loaded onto trucks or conveyer belts, and carried away to a preparation plant (Squillace, 1990). In addition to the excavation area, most surface mines have a number of structures as part of their operations, including headquarters, preparation plants, storage silos, and maintenance shops for equipment (U.S. Department of Labor, 2007). Martin and Black (1998) report that strip mining is generally one of the most widely used methods of coal removal.

Figure 1: Schematic of typical strip mining components



(National Energy Foundation, n.d.)

Under the Surface Mining Control and Reclamation Act of 1977, mine operators are responsible for restoring their mine sites after mining has occurred (Halofsky, J.E., & McCormick, L.H., 2005). Reclamation involves restoring natural vegetation and drainage in order to return the mine site to a useful area such as farmland, wildlife areas, parklands, or housing developments. The reclamation process actually begins before the first ton of coal is removed (Department of Energy (DOE), 2007). To fulfill mining permit requirements, the coal company must document how sedimentation from the temporarily disturbed areas will be controlled, how ground and surface waters will be protected, how archaeological artifacts that may be encountered will be handled, how wildlife disturbances will be minimized, and how restoration of the soil and vegetation will be achieved (DOE, 2007). Once the coal is retrieved, mining companies then reclaim the land by pushing the removed spoil, the overlying vegetation, soil, and underground layers of rock initially removed, back into the stripped area or into another void created by strip mining. The goal is to return the land as close as possible to its original ecological integrity such that the mined land becomes "a diverse, effective and permanent vegetative cover of the same seasonal variety native to the area of land to be affected, and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area" (Holfsky, J.E. & McCormick, L.H., 2005).

Coal mines in Indiana are primarily located in the southwestern region of the state (Appendix I). A few main types of coal are generally used by coal-fired plants to produce energy: subbituminous, bituminous, and anthracite coal. Subbituminous coal typically contains 35-45% carbon, and accounts for approximately 42% of the coal produced in the United States (EIA, 2007). Bituminous coal is typically 45-86% carbon, and is the most abundant type of coal found in the United States (EIA, 2007). Anthracite coal is 86-97% carbon, and is found primarily in Pennsylvania (EIA, 2007). Coal mined and used in Indian is bituminous, and is almost always used for electricity generation (EIA, 2007). Indiana has 24 permitted and operating coal-fired power plants (Clean Air Task Force (CATF), 2000).

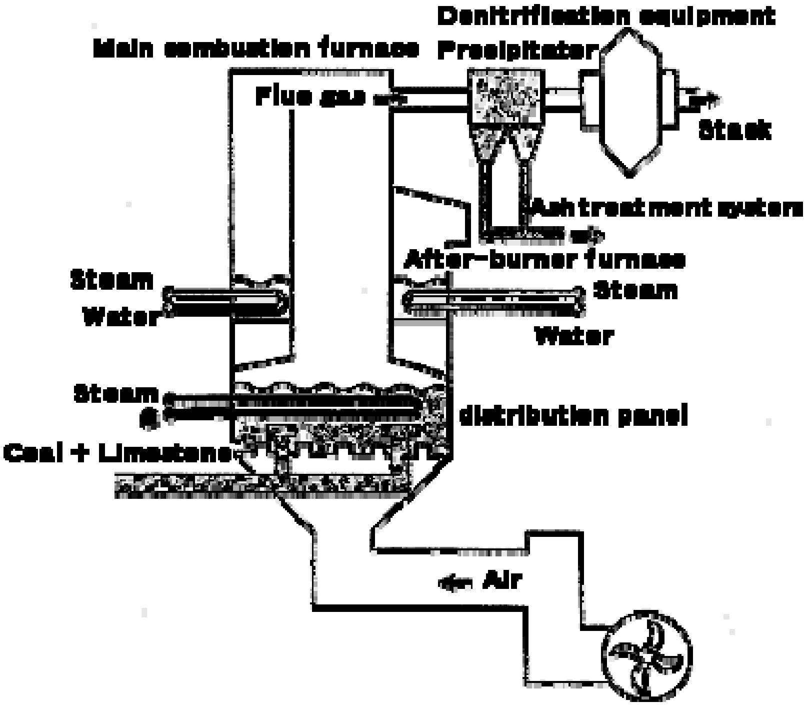
b. Waste Coal Combustion

Waste coal is the left over and rejected remains of coal mined for and utilized in traditional coal plants. Colloquially, the coarse-grained refuse is called “gob”, and the fine-grained refuse is called “tailings” or “slurry” (Harper, Dintaman, Mastalerz, & Letsinger, 2007). It is usually composed of mixed coal, soil, and rock; it is considered mine waste. After the traditional mining of coal, the material that is not high enough quality for use in a coal-fired power plant, the waste coal, is placed back in the mine or dumped into slurry pits. An IGS report states that abandoned mines filled with waste coal have a high content of pyrite, a source of acidic mine drainage (Harper, Dintaman, Mastalerz, & letsinger, 2007). The IGS report (2007) also estimates that there are from 22 to 69 million tons of recoverable coal, waste coal, in Indiana mines. This recoverable waste coal can be a cheap source of fuel for electricity generation.

Because it is composed of mine waste, waste coal has a higher ash content, higher moisture content, and lower heating value than coal (EPA, 1993). Consequently, it must be utilized differently than coal in traditional coal-fired power plants. Waste coal is used to produce electricity in a circulating fluidized bed (CFB) system. Fluidized beds suspend solid fuels on upward-blowing jets of air during the combustion process. The result is a turbulent mixing of gas and solids (Figure 2). The tumbling action, much like a bubbling fluid, provides more effective chemical reactions and heat transfer (DOE, 2007).

The solid waste coal fuel is mixed in the airflow with sorbent technology scrubbers such as limestone which removes sulfur dioxide waste during the combustion process. Additionally, the temperature only reaches 1600˚F, not hot enough to produce nitrous oxide wastes.

Figure 2: Schematic of circulating fluidized bed system



(Global Environment Center Foundation, 1995)

Waste coal combustion is not a common means of electricity generation. Pennsylvania is the only state to have fully embraced waste coal combustion, although West Virginia has also begun utilizing waste coal combustion. The Anthracite Region Independent Power Producers Association (ARIPPA) has 14 Pennsylvania coal waste combustion plants, and three West Virginia waste coal combusting plants using CFB technology. Pennsylvania has led the way in coal waste combustion as a means of reclaiming abandoned mines by utilizing the waste coal that had built up since the industrial revolution and then returning the alkaline ash to the mine to neutralize the acidic leachate. The ash from waste coal combustion is alkaline due to the limestone added during combustion to trap the sulfur dioxide produced. Small power plants began using waste coal in the 1980’s as an energy source, and since then Pennsylvania has utilized over 100 million tons of waste coal and reclaimed over 3800 acres of abandoned mines (ARIPPA, 2008).

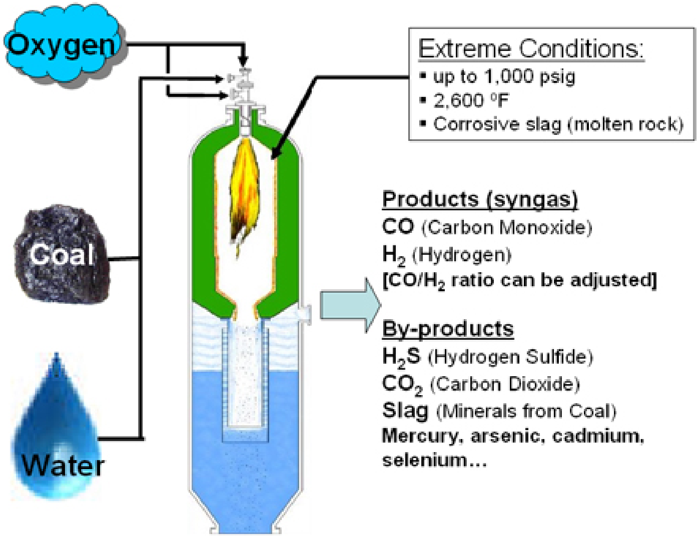
Waste coal combustion has limitations for utilization. Although the US Department of Energy (DOE) National Energy Technology Laboratory has conducted research on CFB technology to determine its safety and effectiveness, the composition of waste coal varies greatly based on the carbon content and the amount of soil, rock, and other components in the mix. The carbon content determines the energy content for combustion. The IGS report also found differences in waste coal composition based on whether the waste coal was from surface or underground mines (Harper, Dintaman, Mastalerz, & letsinger, 2007). The waste coal site needs to be within 50 miles of the combustion facility and accessible to transportation equipment to be economically feasible (Western PA Coalition for Abandoned Mine Reclamation, 2003).

c. Coal Gasification

Traditional pulverized coal technology used to generate energy is both inexpensive and well proven. With no shortage of coal on the horizon, and a lack of attention by state legislatures to the public health effects of traditional coal burning technology, an all-out switch to less demonstrated, less widely implemented, alternative energy source such as coal gasification seems unlikely, despite the fact that the EPA considers it to be one of the most promising technologies in reducing environmental consequences of generating electricity from coal (EPA, 2006).

Integrated gasification combined cycle (IGCC) is the thermal conversion of carbon-based materials at 1,400-2,800°F, with a limited supply of pure oxygen, to a synthetic gas, or “syngas.” Coal is the main feedstock utilized to generate energy in this manner. Coal gasification, therefore, entails heating and partially oxidizing coal with oxygen and steam. The resulting syngas (primarily hydrogen and carbon monoxide), is cooled, cleaned, and fired in a gas turbine-generator. (EPA, 2006). Figure 3 provides a schematic of the gasification process.

Figure 3: Gasification Schematic



Although coal gasification technology can work with three forms of coal (bituminous, subbituminous, and lignite), existing coal gasification plants have used exclusively bituminous coals. It is generally accepted that, by removing most of the pollutants from the syngas prior to combustion, IGCC is capable of meeting more stringent emission standards than pulverized coal technologies (EPA, 2006). IGCC is also more capable of CO_2 capture for sequestration without large costs and energy compromises (EPA, 2006).

A variety of technologies exist at each major phase in the gasification and energy production process. First, there are three types of gasifiers. Moving-bed gasifiers are comprised of a bed of crushed coal that is supported by a grate and the reaction between coal, oxygen, and steam take place within this bed. (EPA, 2006). There are also fluidized-bed gasifiers, which have a discrete bed of crushed coal, but the coal particles are kept in a constant motion by the upward gas flow (EPA, 2006). Finally, the most commonly utilized variation is known as an entrained-flow gasifier. The entrained-flow gasifier utilizes finely pulverized coal particles, which concurrently react with steam and oxygen with very short residence time. These gasifiers operate at high temperature where the coal ash becomes a liquid slag. This process avoids tar formation and its related problems (EPA, 2006), although there have not been any scientific studies documenting variations in emissions based on the type of gasifier utilized.

The second form of variable technology is the coal feeder. Slurry feed gasifiers are used for bituminous coal. In this process, coal is crushed and mixed with water to produce slurry that is 65 – 70% coal by weight. The slurry is pumped into the gasifier with oxygen producing a raw gas mainly composed of H_2, CO, CO_2, and H_2O. The hot syngas leaves the gasifier and enters a radiant syngas cooler where it is cooled to about 1400° F (from 2300 + F), and, in the process, produces high pressure steam. Molten slag is solidified and removed, and the syngas is sent to a convective syngas cooler for additional steam generation. The cooled gas is sent to the acid gas removal plant (EPA, 2006). A solid feed gasifier is used for lignite coal. This process utilizes a dry-feed, pressurized, oxygen blown, entrained-flow slagging reactor. The coal is pulverized and dried prior to being fed into the gasifier. Nitrogen is used as the coal transport gas. Raw fuel gas is produced from high temperature gasification reactions and flows upwardly with some entrained particulates. The high reactor temperature converts the remaining ash into a molten slag, which flows down the walls of the gasifier and passes into a slag quench bath (EPA, 2006). The efficiency of the IGCC non-capture is as follows: the dry-fed Shell gasifier (41.1%), the slurry-fed, two stage CoP gasifer (39.3%) and the slurry-fed, single-stage GEE gasifier (38.2%). (DOE/EPA, 2007).

d. Tire Incineration

Tires from vehicles can also be used as a supplemental fuel for energy production. There are different ways tires can be processed to be used as fuel: whole tires, or shredded tires called tire-derived fuel (TDF). At the end of 2005, 117 separate facilities in the United States were permitted to use scrap tires as fuel: 47 were cement kilns and 22 were electrical utility boilers (Rubber Manufacturers Association (RMA, 2006). In 2003, the Environmental Protection Agency reported that there are at least 290 million scrap tires generated, about one per person, in the United States and approximately 130 million were used for TDF (EPA, 2007). The RMA (2006) reported that in 2005, 155.09 million tires, or 52% of scrap tires, went to the TDF market. Of the tires that were used, 41% went to the cement industry and 18% were used for electricity generation (RMA, 2006). Indiana generates 6.5 million scrap tires per year (Indiana Department of Environmental Management (IDEM), 2007). The use of TDF is an expanding industry.

The tire has many characteristics that make it a desirable fuel additive. Eighty-eight percent of a tire is carbon and oxygen with low moisture content. This allows for rapid combustion at high heat. Thus, tires produce a considerable amount of energy, about 15,000 BTU's per pound (Scrap Tire Management Council, 1992). This is about 25-50% higher than coal (EPA, 2008). Tires are made of rubber both natural and synthetic, sulfur compounds, silica, phenolic resin, various oils, petroleum waxes, various synthetic fabrics, carbon black, pigments including zinc oxides and titanium dioxide, fatty acids, other inert materials, and a steel belt (Rubber Manufacturers Association, n.d.). Thus, tires contain many chemicals that when burned release emissions of environmental health concern, such as complex carbon compounds, many heavy metals including high levels of zinc and iron, chlorinated compounds, sulfur compounds, and nitrogen (EPA, 1997). Tires that are shredded or chipped, known as tire-derived fuel (TDF), are preferable to whole tires. Not only is TDF easier to feed, but it burns more efficiently and combusts more completely. TDF is used as a supplemental fuel with 20% TDF being a general upper limit to keep emissions within limits (EPA, 1997). Facilities must meet all usual emissions limits and monitoring requirements for the particular industry, such as those set by the national emission standards for hazardous air pollutants (NESHAP) and their air quality permits regardless of whether they are supplementing their fuel with tires or not. This requires them to use pollution control devices that allow them to reach these levels (EPA, 2008). In Indiana, staying within capped emission limits, not the fuel type, dictates the necessary pollution control devices a particular burn unit must have (S.A. Flum, director, community relations, Office of External Affairs, IDEM, personal communication, July 25, 2008). There are only two facilities in Indiana permitted to burn tires. Consolidated Grain and Barge in Mt. Vernon is permitted to use shredded tires to supplement their two wood-fired boilers and Lone Star Cement in Greencastle, is permitted to use chipped tires along with many other solid and hazardous wastes. One other cement kiln is considering the technology (S.A. Flum, personal communication, July 22, 2008).

Cement producers are the largest sector using tires for energy. In 2005, 47 cement kilns were using TDF in 78 kilns (Rubber Manufactures Association, 2006). Simply put, in modern dry or semi-dry cement making, the kiln is used to pyroprocess the ground and dried raw materials of cement, mostly limestone, chalk, and clay. The kiln is tilted at a 3-4 degree angle and rotates at about 1-3 times per minute. The prepared raw materials enter the top and as they pass through the kiln are dried further and the carbonate components are calcined. At the bottom, or flame end, of the rotary kiln is the sintering or clinkering zone that reaches temperatures between 3300-3600°F. This is where the cement minerals referred to as clinker are formed. The clinker is then cooled rapidly and ground with some additives to become powdered cement (Coito, Powell, Worrell, Price, and Friedmann, 2005). Tire incineration is favorable for the cement kiln because the positive oxygen environment and extremely high temperatures, in excess of boilers for other industries, provide a good environment in which to completely combust the tires. The use of whole tires is possible in kilns and the removal of the steel belt is not necessary as the zinc and iron are incorporated into the clinker. This not only is economically desirable, but also results in a small amount of residual bottom ash that is not contaminated with excess zinc and iron which is a disposal issue for other industries that cannot utilize the tire components in their processes (EPA, 2008).

For comparison to the other technologies herein analyzed, the use of tires to produce electricity will also be considered. There are various configurations of electrical boilers that fire numerous types and combinations of fuels. These differences affect the desirability for TDF as a fuel for these facilities. For certain electrical boilers, tires must be shredded and de-wired because the boiler has no use for the steel belt and the boiler configurations cannot handle whole tires. Often, the iron, zinc, and other metal components create a contaminated ash disposal issue (EPA, 1997). The most common type of electrical boiler in Indiana is the pulverized coal – dry bottom boiler (D. Hancock, Senior Environmental Manager, IDEM Office of Air Quality/Compliance Branch, July 22, 2008). For this type of boiler the coal is ground to a powder that is blown in a stream of air through burners, to a combustion chamber. A dry-bottom configuration uses coals with high fusion temperatures that allows for fewer ash issues (Clark, Meardon, and Russell, 1991). The Rubber Manufacturers Association (2006) states that “TDF is incompatible with pulverized coal boilers due to the differences between the two fuels, both in terms of size and in terms of the necessary residence time in the combustion zone." It is possible if the TDF is ground to crumb of less than one inch in diameter, the boiler contains a bottom dump grate, the proportion is limited to 20% TDF, and it is burned with a high quality coal to offset the decrease in fusion temperature caused by the high iron content. Using TDF in these boilers is inefficient because the excess air that is needed to burn TDF outweighs the benefits. (Clark, Meardon, and Russell, 1991). Air must be added or the pulverized-flame combustion method must be use to control poly-aromatic hydrocarbon emissions that are a major problem for TDF use in pulverized coal boilers. Reducing TDF to the necessary size is difficult and not cost effective. Therefore, TDF favors other types of electrical boilers, particularly cyclone, stocker, and fluidized bed boilers (Caponero and Tenorio, 2002).

Methodology

The Hoosier Environmental Council (HEC) assigned a specific technology or process to each group member. Strip mining was researched by Lauren Stanisic, Waste Coal Combustion by Lindsey Gordon, Coal Gasification by Chris Roberson, and Tire Incineration by Renee Nahrwold. Throughout the course of researching, the team would meet approximately every two weeks to discuss findings and prepare for further investigation. First, group members completed an exhaustive search of the published scholarly literature and government documents, done through the Indiana University library system. Upon completion, due to limited supply of relevant and up-to-date material, group members were required by the HEC preceptors to make direct contact with professionals, academics, government and non-profit agencies, and research bodies to find additional information. Many contacts were suggested by the HEC preceptors or were referred by prior made contacts. This process included phone calls and emails to between 20-40 contacts per group member. Group members experienced an approximately 30-50% response rate from attempted contacts.

As resources were slowly gathered, each group member progressively worked on developing an understanding of his or her assigned technology and a compilation of facts and figures on their environmental health profiles. These drafts included an explanation of the researched technology, charts and graphs demonstrating processes and air emissions, and a discussion on the environmental health impacts. These individual compilations were then synthesized into one comprehensive report culminating with a generalized recommendation statement to inform the public on these options for Indiana.

Results

a. Strip Mining

Unlike waste coal combustion, coal gasification, and tire incineration, the primary environmental health impacts of strip mining are not limited to air quality. Rather, strip mining is a process that affects many elements of nature as it seriously disrupts land through the removal and displacement of natural wildlife, and the use of heavy machinery and explosives. In analyzing land that has been strip mined, Shrestha and Lal (2006) note that,

> [d]espite its economic importance, mining operations completely remove and stockpile soil materials resulting in drastic landscape perturbations. This causes major damage to the whole ecosystem …. Mined soils are often characterized by high bulk density, low pH, low nutrient availability, poor structure, low watering holding capacity, and low biomass productivity (p. 783).

Strip mining causes land degradation because it removes the ground’s layer of topsoil, a process resulting in land that is both unsightly and potentially harmful (Tian et al., 2006). This, in turn, permanently changes the topography, or structure, of the mined area (Shrestha, R.K. & Lal, R., 2006).

Through strip mining, erosion of sediments from the surfaces of strip mined areas is set in motion, sometimes in amounts as much as 1,000 times greater than sediment erosion from undisturbed land (Ohio Department of Natural Resources, n.d.). By disturbing large tracts of land, many sequestered heavy metals are disturbed. These mainly include, but are not limited to, lead, phosphorus, cadmium, and zinc (Martin & Black, 2006).

The heavy erosion of topsoil adversely affects the environment. For example, erosion set forth by strip mining can seriously threaten freshwater ecosystems (Bruns, 2005). Through strip mining, heavy metals may become available to wildlife and fish via mine tailings, the leftover waste materials created during mining. This may occur when rainfall pushes water to runoff from a contaminated site to water bodies serving as sources for recreational activity, irrigation, drinking use, etc. (Martin & Black, 1998).

Martin and Black (1998) conducted a study to determine the effects of coal strip-mine contamination on channel catfish in Oklahoma. The research found that fish exposed to sediments eroded through strip mining had higher levels of heavy metals than unexposed channel catfish, especially lead (Martin & Black, 2006). While the study was strictly limited to the effects of a surface coal mines on channel catfish, the findings present serious public health implications. This study supports that fish and other wildlife, living in water sources near strip mines, can be contaminated by wastes from the mine. Consumption of these fish by human beings could present health problems. For example, lead, as was found in the Oklahoma Channel catfish, is a known human toxin with a variety of adverse health effects such as lowering IQs and causing nerve disorders (National Institute of Environmental Health Sciences, 2005). Further, the Ohio Department of Natural Resources (n.d.) found that these sediments also disrupt the natural ecosystem of these streams by smothering bottom life and destroying vital segments of the aquatic food chain.

Beyond harming aquatic ecosystems, strip mining has also been shown to cause serious problems for general water quality because of acid mine drainage (Tian et al., 2006). The USEPA (2008) reports that acid mine drainage is formed when “water contaminated with pyrite, and iron sulfide, is exposed and reacts with the air and water to form sulfuric acid and dissolved iron... acid runoff further dissolves heavy metals such as copper, lead, mercury, into ground or surface water.” Because the process of surface coal mining disrupts sequestered heavy metals, these toxins are then released into the environment with the potential to contaminate natural water sources. Additionally, a study conducted at the Mount Arthur North coal mine in New South Wales, Australia identified some of the effects of strip mining on groundwater. The study found that, through redirected groundwater flow caused by the strip mining as well as precipitation, water would collect in mined areas and become highly saline. This increased amount of salinity is accumulated through salts from rainfall, weathering of fresh rock, groundwater inflow, and the concentration of salts through evaporation (Hancock, Wright, De Silva, 2004). Unfortunately, while these studies suggest potential harmful impacts to human health due to contaminated drinking water, epidemiologic research does not exist on the subject.

Air pollution released through the process of surface coal mining also presents environmental and public health concerns. Ghose and Majee (2007) report, “… in surface mining, the air pollution problem is acute, particularly with respect to dust pollutants.” To reach coal, massive amounts of overburden must be removed. This may require excavators, loaders, dumpers, conveyor belts, and vehicular traffic, in addition to naturally occurring wind erosion, all of which create immense discharge of fine particulates from overburden materials (Ghose & Majee, 2007). As a result, in a study done by Ghose and Majee (2007), both the coal mining work zones and the ambient air contain high levels of fine particulate matter pollutants that have negative implications for health effects on nearby communities.

Pennsylvania, unlike Indiana, mines anthracite coal. As a result of differing compositions of anthracite and bituminous coal, the health effects of strip mining each type may also differ. Nevertheless, the bulk of public health research assessing health outcomes of coal mining areas in the United States has been conducted in Pennsylvania, and has found significant associations. For example, a study conducted in an Appalachian mining community found that counties characterized by high levels of mining had significantly higher mortality rates than those outside mining areas, even after accounting for the effects of age, smoking, poverty, education, race, and other potential covariates (Hendryx, 2008). In fact, the age-adjusted mortality rate for Appalachian coal mining areas was found to be about 24 years behind national rates outside of those areas in Appalachia (Hendryx, 2008). Additionally, another study conducted in the Pennsylvania coal mining region analyzed hospitalization patterns of residential areas proximate to coal mining areas. The study found that the most common diagnoses were chronic obstructive pulmonary disease and hypertension, and rates of these diagnoses significantly increased as coal mining production increased (Hendryx, Ahern, & Nurkiewicz, 2007). This study concluded that such outcomes were most likely associated with exposure to particulate matter from mining activities (Hendryx, Ahern, & Nurkiewicz, 2007). Finally, a study completed in Liverpool, England, found that children from communities exposed to coal dust had lower mean birth weights, increased prevalence of respiratory problems, and higher frequency of missed school due to asthma than unexposed communities, even when these groups were controlled for having either smoking or non-smoking parents (Brabin et al., 1994).

b. Waste Coal Combustion

Nitrous oxides (NO_x), sulfur dioxides (SO_2), and mercury are toxic air emissions of concern from coal-fired power plants. The toxic air emissions analyzed from waste coal combustion are the same. The technology used for waste coal combustion, circulating fluidized bed technology, has shown lower toxic air emissions than traditional coal combustion in experimental and laboratory settings. However, generalizing the results of laboratory tests to real-life scenarios in Indiana may prove to be inaccurate. Additionally, field data collected from waste coal combustion facilities is from Pennsylvania anthracite waste coal combustion. Consequently, Indiana bituminous waste coal may generate different levels of toxic air emissions.

Data from the Department of Energy's National Energy Technology Laboratory (NETL) on circulating fluidized bed combustion shows lower air emissions for NO_x and SO_2 compared to the New Source Performance Standard, pollution control standards issued by the Environmental Protection Agency (NETL, 2000). Data collected by the Pennsylvania Department of Environmental Protection (PADEP) shows lower emissions for all toxic substances in coal waste combustion plants compared to traditional coal plants. Of particular interest is extrapolated data that predicts mercury emissions to be ten times lower in coal waste combustion plants. Additionally, PADEP has Continuous Emissions Monitoring data for NO_x and SO_2. The Department of Energy NETL reports that circulating fluidized bed systems of combustion meet the 1990 Clean Air Act Amendments (NETL, 2000).

Table 1: Waste Coal Combustion Emission Profiles

Pressurized Fluidized Bed Combustion System	**First Generation Technology**	**Second Generation Technology**
NOx Emissions[1]	**1/3rd**	**1/10th**
SO2 Emissions[1]	**1/4th**	**1/10th**
1990 CAAA[2]	**Yes**	**Yes**
[1] Compared to New Source Performance Standards		
[2] Clean Air Act Amendments		

Based on Department of Energy research, NO_x emissions from circulating fluidized bed combustion systems are 1/3 of New Source Performance Standards for first generation systems, and up to 1/10 the level with second generation CFB systems (See Table 1). In the field, quarterly data from waste anthracite coal combustion plants in Pennsylvania, NO_x emissions are 0.15 lb/MMBtu (PADEP, 2003). A typical pulverized coal facility produces NO_x emissions of 0.3-0.5 lb/MMBtu. This quantifies the NO_x emissions from a coal plant as 2-3 times higher than those from a waste coal combustion facility. The U.S. Department of Energy research shows that this is due to the CFB technology because it burns fuel at temperatures of 1,400 to 1,700^o F, well below the threshold where nitrogen oxides form; at approximately 2,500 ^{o} F, the nitrogen and oxygen atoms in the combustion air combine to form nitrogen oxide pollutants (DOE, 2007).

Department of Energy research on SO_2 emissions from circulating fluidized bed combustion systems show them to also be lower than the New Source Performance Standards; specifically 1/4 with first generation, and up to 1/10 with second generation. Waste anthracite coal combustion plants in Pennsylvania see SO_2 emissions of 0.20-0.25 lb/MMBtu with limestone injection (PADEP, 2003). Pulverized coal facilities have 2-3 lbs/MMBtu of SO_2, but this can be lowered to 0.10-0.40 lb/MMBtu with scrubbers, a filtering technology. The U. S. DOE research shows that this is due to the CFB technology because the mixing action of the fluidized bed results in bringing the flue gases into contact with a sulfur-absorbing chemical, such as limestone or dolomite (DOE, 2007). More than 95% of the sulfur pollutants in coal can be captured inside the boiler by the sorbent.

Mercury is the third toxic air emission of concern from coal plants. Kathleen McGinty, Secretary of the PADEP, reported an 80% decrease in mercury emissions from coal waste combustion plants compared to traditional coal plants (McGinty, 2004). Another report states that mercury emission is 10 times lower in waste coal combustion compared to traditional coal plants (PADEP, 2003).

It is difficult to elucidate the public health and environmental effects of waste coal combustion since epidemiological studies cannot offer insight into a cause-effect relationship with individual emissions. Additionally, there is no published and peer-reviewed literature pertaining to waste coal combustion emissions and resultant health outcomes. However, since the source of waste coal’s energy generation is carbon, the public and environmental health effects of traditional coal-fired power plant emissions of nitrogen oxides, sulfur dioxides, mercury, and particulate matter may provide some insight into possible waste coal combustion health outcomes.

There is evidence that proximity to coal-fired power plants increases adverse health events. A 2005 study conducted on 285 children in Israel found that as particulate matter from coal plants increased, the expiratory rate decreased (Peled et al., 2005). Ash is produced as a byproduct of waste coal combustion and if not captured is released into the air as fugitive dust or particulate matter. A 2004 study in the New England Journal of Medicine linked power plant pollutants with reduced lung development in children in California (Gauderman, et al., 2004). The Gauderman study was based on pollution from automobiles, but the pollutants under consideration included nitrogen oxide which is released from coal-fired power plants and possibly from waste coal combustion.

Further, a 2002 study in the Journal of the American Medical Association determined that exposure to sulfur oxide–related pollution and fine particulate matter over a 16-year period is associated with a 6% increase in the risk of death from cardiopulmonary causes and an 8% increase in the risk of death from lung cancer (Pope et al., 2002). Another long-term study by Wellenius et al., considered 50,000 Medicare beneficiaries and found that daily increases in sulfur dioxide and nitrogen oxide over a 16-year study period resulted in increased hospitalization for congestive heart failure (Wellenius, Bateson, Mittleman, & Schwartz, 2005). These two long-term health studies were retrospective, but can be taken as evidence in favor of precautionary measures against technologies that release these pollutants such as coal-fired power plants and waste coal combustion facilities. A study on the public health effects of mercury released from coal-fired power plants found that it likely accounts for an additional 231 cases of mental retardation in children in the United States every year (Trasande, Schechter, Haynes, & Landrigan, 2006). This study again demonstrates the need for technology that has lower toxic air emissions. There is strong evidence in these and many other studies that the emissions from coal-fired power plants, the profile of which can be similar to waste coal combustion, has the potential to cause respiratory, cardiovascular, and neural deficiencies.

c. Coal Gasification

Integrated coal gasification combined cycle (IGCC) has a much smaller environmental footprint for air emissions and waste than traditional coal combustion (Clean Air Task Force, 2007). IGCC reduces deadly sulfur and nitrogen oxide emissions to very low levels – approaching those achievable by natural gas combined cycle power plants. Gasification is the *only* coal power generation technology that can virtually eliminate mercury air emissions and capture most of the coal mercury content in a concentrated form that can potentially be sequestered from environmental release. Total solid waste from gasification is typically half the volume generated by conventional coal plants and gasification water use is substantially lower as well (Clean Air Task Force, 2007).

Coal gasification captures greater than 98% of generated sulfur. H_2S and COS are removed from the syngas in an amine-based scrubber prior to combustion and recovered as elemental sulfur or sulfuric acid. Both are salable industrial commodities. Nitrogen Oxides are mainly converted to N_2 and small amounts of NH_3 and HCN, however HCN can be removed from the syngas. Diluents, such as nitrogen and steam, are used in the gas turbine to lower the combustion flame temperature to minimize NO_x generation. Virtually all particulate matter is removed in the coal gasification process. Fly ash entrained with syngas is removed downstream in a wet scrubber. There have been no documented problems with acid mist.

Carbon Dioxide (CO_2) is perhaps the most well-known greenhouse gas. The higher thermodynamic efficiency of IGCC cycle minimizes CO_2 emissions relative to other technologies and the high pressure and high CO_2 concentration in syngas provides optimum conditions for CO_2 removal prior to combustion. This process, known as carbon capture and sequestration, has cost and energy penalties in the range of $0.019/kWh and 0.3E+09 kWh/yr respectively, compared to coal gasification without carbon capture technology (Bergerson, 2007). Slag material is environmentally benign and can be safely landfilled. Slag can also be safely utilized for various applications, such as drainage material or roofing granules, similar to material produced by wet-bottom PC plants.

The average emissions from twelve coal gasification have been reported by the National Technology Laboratories (NETL) (2002) are reported in table 2.

Table 2: Emissions of select pollutants from coal gasification.

Emission	**Volume**
SO_2	0.08 lb/MMBtu
NO_x	0.6 lb/MMBtu
PM	0.006 lb/MMBtu
CO2	1.76 – 1.6 lb/kWh
Hg	90-95% removal
Solid Waste	218 lb/MWh

These gasification plants include six IGCC cases utilizing General Electric Energy (GEE), ConocoPhillips (CoP), and Shell gasifiers each with and without CO2 capture; four PC cases, two subcritical and two supercritical, each with and without CO_2 capture; and two NGCC plants with and without CO_2 capture.

There are only two existing plants in the United States; SG Solutions/PSI Energy, located in West Terra Haute, IN (262 MW) and the Polk Power Station, located in Tampa, FL. (250 MW). Duke Energy has proposed construction of a coal gasification plant in Edwardsport, IN, but the proposal has not yet been approved. There are only 6 additional gasification facilities operating worldwide (Newcomer, 2007).

d. Tire Incineration

It is common knowledge that the uncontrolled burning of scrap tire piles is unpleasant and toxic to both the environment and public health. This and the other negative public health effects of waste tire piles, such as being a breeding ground for potentially disease carrying mosquitoes, make alternative uses for scrap tires desirable. Landfilling tires, as is Indiana's number one disposal route, also results in negative environmental and potential public health problems (Indiana Department of Environmental Management [IDEM], 2008). These environmental and public health issues and various economic incentives, particularly for the Portland cement industry, pose a strong argument for tires to energy technology (Scrap Tire Management Council, 1992). However, none of these arguments involve an analysis of the potential environmental health outcomes of actually incinerating tires for energy recovery.

Generally, the argument for tires to energy is based on a comparison of certain air emission levels when burning tires to levels when not burning tires. This argument usually states that incinerating tires produces less NOx and similar SOx emissions, and variable or lower heavy metals in ash emissions, especially in cement kilns. Thus, since the emissions are comparable to those of coal alone, especially with the application of pollution control devices and the fact that the same emissions limits and requirements must be met, there is no risk associated with TDF (EPA, 2008). However, to truly determine if the emissions from a facility will result in any human health effects, one must analyze the actual dose an individual takes in. This makes the data significant to public health. The amount emitted and the percent change in emissions are not statistics that directly assess the public health impact. The concentrations at ground level are because they measure the amount that a person could actually be inhaling. Although few analyses have done so, a risk assessment should take place to assess the effect a facility's utilization of TDF may pose to the health of residents in the surrounding community (U.S. Department of Health and Human Services [HHS], 2003).

A risk assessment of this type was done by the Boulder County Public Health Department (BCPH) in Lyons, CO as a response to concerns voiced by the community about the local CEMEX cement plant's intention to begin utilizing TDF. The BCPH asked the Agency for

Toxic Substances and Disease Registry (ATSDR) to analyze the comparative risk assessment that they had conducted in the community. In conducting this risk assessment, the potential routes of exposure were determined. In the case of incinerating TDF, this is mainly inhalation from air emissions. The concentrations of each compound, recorded from stack tests at the facility, were then compared to known health comparison values to select for contaminants that required further evaluation. If a compound is found to exceed the comparison, it simply means that, "if someone stuck their head in the stack and breathed in, these chemicals might cause health effects (HHS, 2003)." Air dispersion modeling was done to determine the concentrations at ground level. Such modeling requires knowledge of stack height, diameter, base elevation, location, stack gas velocity and exit temperature on the date of measurement, one year hourly meteorological data at the plant site, and building downwash effects. The modeling resulted in dispersion factors that allowed for the calculation of average and maximum 1-hour, 24-hour, and annual ground level concentrations for the maximally exposed individual resident for each compound. None of these numbers were above corresponding pre-set health comparison values. Thus, it was determined that health effects were not likely. ATSDR, EPA, and the American Conference of Governmental Industrial Hygienists (ACGIH), provide comparison values for acute, chronic, quarterly, and/or carcinogenic values for most compounds of concern (HHS, 2003).

There are many factors that effect emissions. Even these factors vary by industry, type of equipment, and main fuel being supplemented by TDF. Factors may include size of TDF, wired or de-wired, change in proportion TDF/main fuel, additional fuels being used, their characteristics and relative proportions, location or rate of fuel feed, manner of fuel feed, type and design of the burn unit, temperature and time in the unit, time in contact with the flame, amount of oxygen in unit, turbulence of unit, type of pollution controls, temperature of pollution controls, and characteristics of the materials being heated (HHS, 2003). Differences among these factors make emissions comparisons between industries impossible and comparisons between facilities within an industry difficult. Thus, for the purposes of this paper, the results from one typical cement kiln and one typical electrical boiler designed similar to those in Indiana and that supplement TDF with coal will be analyzed.

Since data was obtained that is applicable for public health, the data from the above mentioned CEMEX study will be provided as an example of the environmental health impact of a typical cement kiln. Stack test data was analyzed both without tires and with 19.2% whole tires and resulted in seventeen compounds that were above the health comparison values and thus further evaluated. These compounds were NOx, SOx, particulates, CO, HCl, acetaldehyde, benzene, formaldehyde, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, and nickel. This did not mean that these chemicals posed a risk to human health only that these chemicals were over health values in the stack, but not necessarily in the breathable air. After modeling of these seventeen compounds, ATSDR concluded that none of the chemicals, when burning tires or not, posed a risk to the health of residents in nearby communities (HHS, 2003). The average and maximum ground level concentrations and the corresponding health comparison values for the seventeen compounds listed above are shown in Appendix II (copied directly from HHS, 2003).

No specific emissions data were found for a pulverized coal utility boiler. Caponero and Tenorio (2002) report that studies in controlled laboratory-scale test settings have shown that tire crumb releases 3-5 times less NOx, 10% less CO_2, comparable $SO_{2,}$ and more PAH’s than pulverized coal. However, no conclusion on risk to human health can be derived from this generalization. There was another test done on April 23-27, 2001 by Mostardi-Platt, Inc in Purdue University's boiler #2, which is a stocker boiler. (S.A. Flum, personal communication, July 25, 2008). This test looked at emissions differences when burning 5% TDF as compared to 100% coal for particulate matter both filterable and un-filterable, visible emissions, SO_2, NOx, CO, HCl, HF, dioxins/furans, VOC's, and metals without use of any pollution controls. The test burn found that supplementing TDF slightly increased performance, condensable particulates, opacity, NOx, dioxins/furans, HCl, and various metals. Aluminum and zinc had large increases as would be expected due to the fact that the facility was testing whole tires. Detected levels decreased for filterable particulates, SO_2, CO, VOC's, and manganese (S.A. Flum, personal communication, July 25, 2008). A summary of these results can be found in Appendix III. The situation tested is nothing like it would be from a real electrical boiler; the test conditions were highly controlled and no pollution controls were used. Thus, extrapolation of these data to an actual stocker boiler using TDF is not possible. Considering this and the fact that a risk assessment to obtain levels in the breathable air was not conducted, these data are essentially meaningless for environmental health assessment purposes. At the very least facilities need to keep their emissions within set limits by utilizing and maintaining the proper pollution control devices and following all monitoring requirements. This should make the emissions from incinerating TDF comparable to the emissions when incinerating just coal. This is assumed to extrapolate to a comparable risk to the environment and public health. However, it is possible to get stronger data more applicable to public health. Ideally, a risk assessment complete with modeling to compare breathable levels with health risk values would be done for all facilities burning TDF to ensure the environmental health of the surrounding communities.

Conclusions

This study suffered many limitations. A lack of epidemiologic research and a dearth of data exist on the studied technologies. Strip mining has been utilized as a method for extracting coal for many years. However, while copious studies have been done on the environmental effects of coal mining, very few studies have been conducted on the public health outcomes of these effects. Further, a variety of coal is found in the United States, each type having a unique composition. The sole public health studies conducted on the public health effects of strip mining were completed in Pennsylvania, an anthracite coal region. As Indiana's coal is bituminous coal, not anthracite, it would be inaccurate to generalize the conclusions found from the anthracite coal studies to Indiana. As a result of these factors, it was very difficult to make direct conclusions about the public health effects of surface coal mining in Indiana.

Waste coal combustion, as an energy generating technology, has been in use since 1980. It has thus far only been used in the anthracite coal regions of Pennsylvania and West Virginia on a commercial scale. Therefore, emissions data taken from these areas is inaccurate for Indiana. Within Indiana, bituminous waste coal has also been found to have highly variable compositions, making estimates on possible emission profiles of combustion very difficult to draw. Since the emissions from waste coal combustion are similar to that of coal combustion, it was necessary to base public health conclusions on the effects of coal combustion rather than strictly waste coal combustion. It is uncertain if these conclusions can be accurately generalized to waste coal combustion as well.

The major limitation to evaluating coal gasification technology was a lack of both peer reviewed literature documenting emission profiles and public health considerations, and a lack of widespread and demonstrated utilization of the technology. Government publications indicate that energy production from coal gasification-derived syngas can offer improved emission controls over other coal-fuel technologies such as pulverized coal facilities, reducing CO_2 by 85-90% with emission rates near 95 kg CO_2/MWh (Newcomer, 2007). However, the lack of demonstrated coal gasification facilities, specifically those taking advantage of the CO_2 capturing technology, has lead to the reluctance of many policy makers and environmentalist to endorse coal gasification as a viable alternative mechanism for generating energy.

Most of the data on tires used for energy is taken from the required emissions profiles completed by industry to acquire and maintain permits. The emissions are not continually monitored for most compounds, therefore the data obtained are taken in optimal conditions and are thus best case scenarios and are unlikely to be the reality at most facilities. Many emissions are not measured at ground level and are thus not generalizable for public health purposes. As a result, these numbers do not represent the dose of a compound to which the general public is typically exposed. The most desirable data would be from an epidemiologic study, which would be highly complex and difficult to conduct because of the inherent challenge in linking specific compounds with specific health issues, and specific fuels with specific emission contaminants.

Finally, the scope of this project was beyond that which could be accomplished in the given time period. Due to the variability of coal types and variability within each type of studied technology, it is not possible to draw general inferences about these technologies in aggregate. Filtering through these different options was time consuming, and made it difficult to find information that is directly relatable to Indiana.

Recommendations

To truly evaluate the public health effect of these technologies, an initiative much be launched to monitor the emission profiles and subsequent public health effects of these methodologies. This study must be conducted specifically in terms of measuring the dosage of emissions to which the public is directly exposed, such that public health conclusions could then be both concretely drawn and kept within preexisting ambient air quality standards. Only once such studies have been conducted in Indiana, or other regions containing bituminous coal, can true public health associations be measured.

Strip mining is an intrinsic component of coal mining in Indiana. Rather than an alternative energy production technology, the environmental and public health effects of strip mining should be included in any assessment of traditional or alternative coal technology. When these effects are considered, even the cleanest coal technologies, such as gasification, pale in comparison to much more sustainable and renewable energy resources such as wind, solar, geothermal, and biomass.

Diverting waste coal during abandon mine reclamation has obvious environmental and subsequent public health benefits. In addition, the lack of published evidence demonstrated an increased health risk from combusting waste coal may lead policymakers to consider similar tax incentives for waste coal combustion. Because of the similar environmental profiles between waste coal combustion and traditional coal technology, however, waste coal should not be deemed a “clean coal” technology.

Coal gasification can offer substantial improvements to the environmental profile of coal combustion. A lack of peer reviewed literature demonstrating decreased health risks from this technology compared to traditional coal combustion will legitimately concern environmentalists. The CO_2 capturing technology capable of being utilized in conjunction with coal gasification, and the ability to remove other contaminates from the syngas prior to combustion makes this technology one that should be given serious consideration by policy makers. With CO_2 cap and trade systems being proposed by both of the major presidential candidates, coal facilities should weigh the likely price for future CO_2 emission (estimated to be approximately $50/ton in 2020) against the investment cost of building a IGCC facility. A carbon price below $40/ton is unlikely to produce investments in carbon capture for electric power. (Patiño-Echeverri D, 2007).

Considering the economic incentive and the positive effect on the environment and public health from the diverting of scrap tires out of piles and landfills and the fact that there is currently no strong evidence that tire incineration causes a considerable risk as compared to coal; tire derived fuel is an acceptable option as long as all emissions limits and requirements are met through the application of appropriate pollution control devices. If the government provides market incentives for companies to incinerate tires, it is likely that tire incineration will become much more common in Indiana. Given the variety of alternative uses for scrap tires, the economic advantages that utilizing tires provides for the cement industry, the fact that TDF is a poor choice for the majority of Indiana’s electrical boilers, and the uncertainty regarding the public health effects of tire incineration, these incentives are not recommended.

Further, a second phase of this project would be beneficial as the scope of the current project was such that a few beneficial tasks could be not completed. This could include pursuit of primary data from communities proximate to the technologies under study. Such information would provide first-hand accounts of the health effects of these facilities. Additionally, a precise comparison of the alternative technologies’ emission and environmental profiles with those from traditional coal technologies would provide an important tool in measuring the relative impacts of each.   Finally, the alternative technologies considered in the project are not the most optimal choices in terms of public health. While each technology under consideration provides a lesser public health concern than traditional coal energy generating technology, both wind, solar, geothermal, and biomass power provide methods of energy production that have little to no impact on air quality and are sustainable, which is an important quality all of the herein studied technologies lack. As a result, these methods are strongly recommended for examination as a continuation of this project as well as consideration by Indiana legislature.

Appendix I – Indiana Coal Mines

Index map of Indiana showing the coal-bearing rocks of the Pennsylvanian System in green, underground coal mines in blue, and surface coal mines in brown.

Source: Indiana Geological Survey

http://igs.indiana.edu/Geology/maps/coal/cmis/images/state_index.jpg

Appendix II - Health Risk Assessment Average and Maximum Breathable Air Values for CEMEX Plant in Lyons, CO

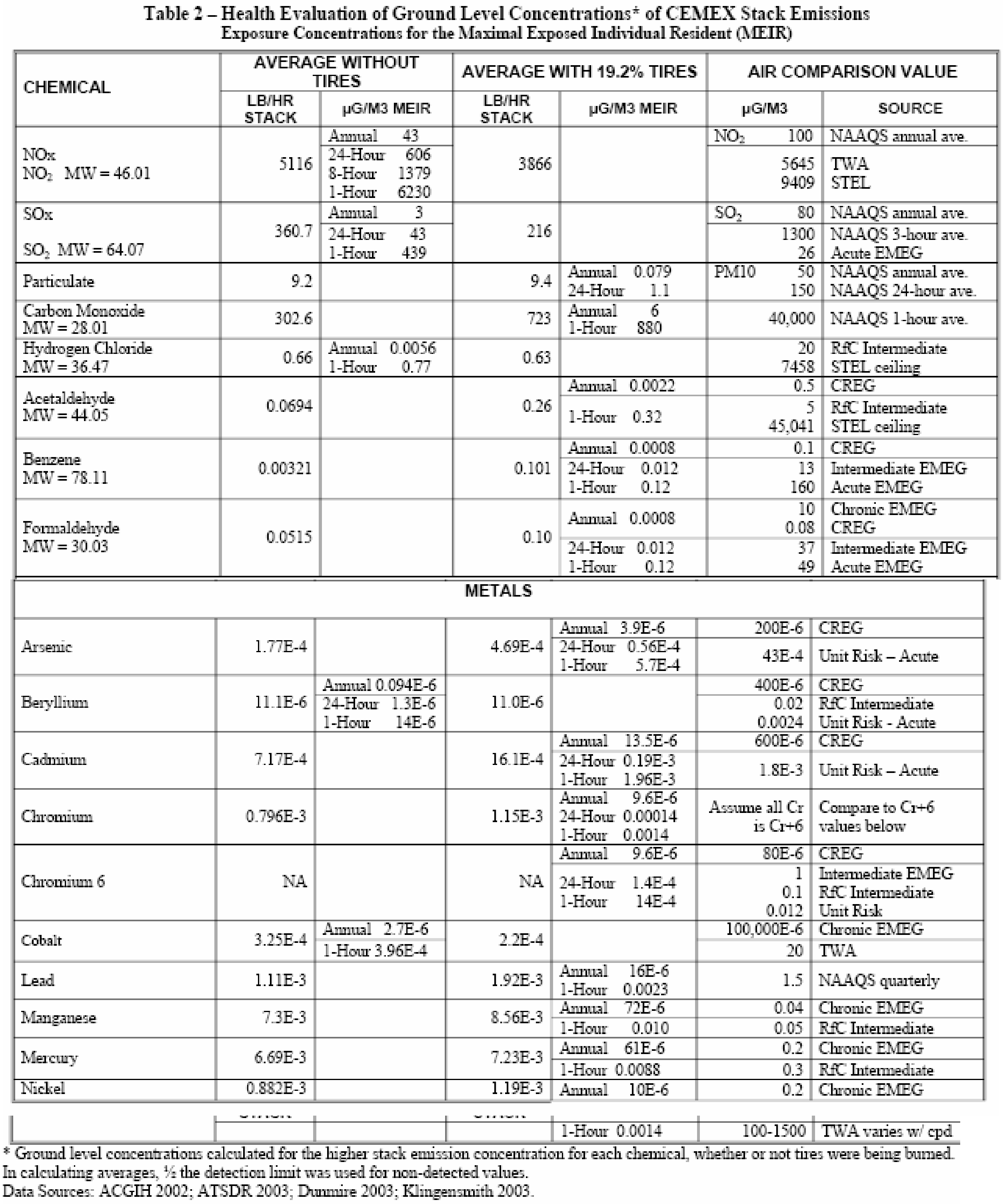


Table 2 – Health Evaluation of Ground Level Concentrations* of CEMEX Stack Emissions
Exposure Concentrations for the Maximal Exposed Individual Resident (MEIR)

CHEMICAL	AVERAGE WITHOUT TIRES		AVERAGE WITH 19.2% TIRES		AIR COMPARISON VALUE	
	LB/HR STACK	µG/M3 MEIR	LB/HR STACK	µG/M3 MEIR	µG/M3	SOURCE
NOx NO_2 MW = 46.01	5116	Annual 43 24-Hour 606 8-Hour 1379 1-Hour 6230	3866		NO_2 100 5645 9409	NAAQS annual ave. TWA STEL
SOx SO_2 MW = 64.07	360.7	Annual 3 24-Hour 43 1-Hour 439	216		SO_2 80 1300 26	NAAQS annual ave. NAAQS 3-hour ave. Acute EMEG
Particulate	9.2		9.4	Annual 0.079 24-Hour 1.1	PM10 50 150	NAAQS annual ave. NAAQS 24-hour ave.
Carbon Monoxide MW = 28.01	302.6		723	Annual 6 1-Hour 880	40,000	NAAQS 1-hour ave.
Hydrogen Chloride MW = 36.47	0.66	Annual 0.0056 1-Hour 0.77	0.63		20 7458	RfC Intermediate STEL ceiling
Acetaldehyde MW = 44.05	0.0694		0.26	Annual 0.0022 1-Hour 0.32	0.5 5 45,041	CREG RfC Intermediate STEL ceiling
Benzene MW = 78.11	0.00321		0.101	Annual 0.0008 24-Hour 0.012 1-Hour 0.12	0.1 13 160	CREG Intermediate EMEG Acute EMEG
Formaldehyde MW = 30.03	0.0515		0.10	Annual 0.0008 24-Hour 0.012 1-Hour 0.12	10 0.08 37 49	Chronic EMEG CREG Intermediate EMEG Acute EMEG
METALS						
Arsenic	1.77E-4		4.69E-4	Annual 3.9E-6 24-Hour 0.56E-4 1-Hour 5.7E-4	200E-6 43E-4	CREG Unit Risk – Acute
Beryllium	11.1E-6	Annual 0.094E-6 24-Hour 1.3E-6 1-Hour 14E-6	11.0E-6		400E-6 0.02 0.0024	CREG RfC Intermediate Unit Risk - Acute
Cadmium	7.17E-4		16.1E-4	Annual 13.5E-6 24-Hour 0.19E-3 1-Hour 1.96E-3	600E-6 1.8E-3	CREG Unit Risk – Acute
Chromium	0.796E-3		1.15E-3	Annual 9.6E-6 24-Hour 0.00014 1-Hour 0.0014	Assume all Cr is Cr+6	Compare to Cr+6 values below
Chromium 6	NA		NA	Annual 9.6E-6 24-Hour 1.4E-4 1-Hour 14E-4	80E-6 1 0.1 0.012	CREG Intermediate EMEG RfC Intermediate Unit Risk
Cobalt	3.25E-4	Annual 2.7E-6 1-Hour 3.96E-4	2.2E-4		100,000E-6 20	Chronic EMEG TWA
Lead	1.11E-3		1.92E-3	Annual 16E-6 1-Hour 0.0023	1.5	NAAQS quarterly
Manganese	7.3E-3		8.56E-3	Annual 72E-6 1-Hour 0.010	0.04 0.05	Chronic EMEG RfC Intermediate
Mercury	6.69E-3		7.23E-3	Annual 61E-6 1-Hour 0.0088	0.2 0.3	Chronic EMEG RfC Intermediate
Nickel	0.882E-3		1.19E-3	Annual 10E-6 1-Hour 0.0014	0.2 100-1500	Chronic EMEG TWA varies w/ cpd

* Ground level concentrations calculated for the higher stack emission concentration for each chemical, whether or not tires were being burned. In calculating averages, ½ the detection limit was used for non-detected values.
Data Sources: ACGIH 2002; ATSDR 2003; Dunmire 2003; Klingensmith 2003.

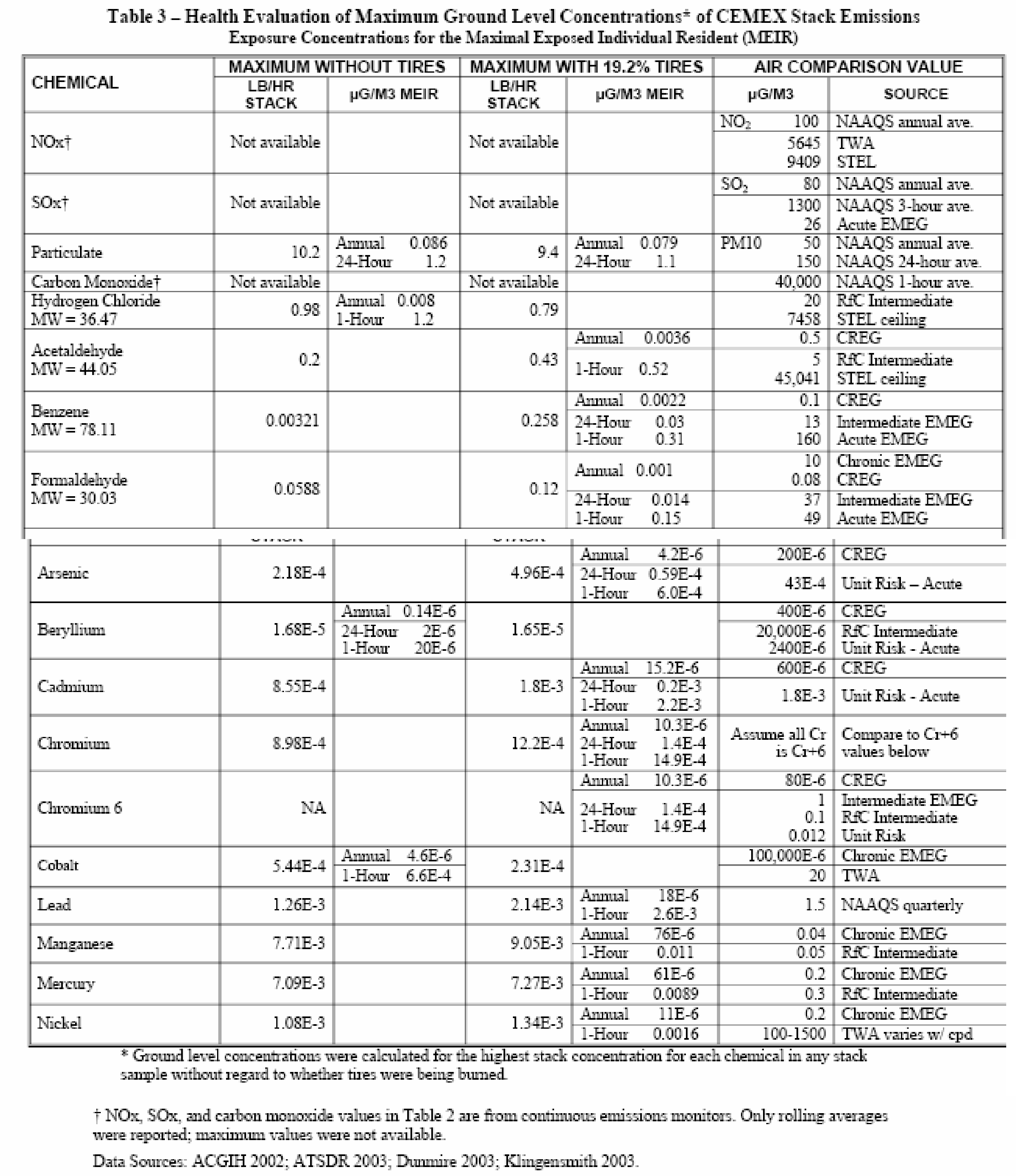


Table 3 – Health Evaluation of Maximum Ground Level Concentrations* of CEMEX Stack Emissions

Exposure Concentrations for the Maximal Exposed Individual Resident (MEIR)

CHEMICAL	MAXIMUM WITHOUT TIRES		MAXIMUM WITH 19.2% TIRES		AIR COMPARISON VALUE	
	LB/HR STACK	µG/M3 MEIR	LB/HR STACK	µG/M3 MEIR	µG/M3	SOURCE
NOx†	Not available		Not available		NO$_2$ 100 5645 9409	NAAQS annual ave. TWA STEL
SOx†	Not available		Not available		SO$_2$ 80 1300 26	NAAQS annual ave. NAAQS 3-hour ave. Acute EMEG
Particulate	10.2	Annual 0.086 24-Hour 1.2	9.4	Annual 0.079 24-Hour 1.1	PM10 50 150	NAAQS annual ave. NAAQS 24-hour ave.
Carbon Monoxide†	Not available		Not available		40,000	NAAQS 1-hour ave.
Hydrogen Chloride MW = 36.47	0.98	Annual 0.008 1-Hour 1.2	0.79		20 7458	RfC Intermediate STEL ceiling
Acetaldehyde MW = 44.05	0.2		0.43	Annual 0.0036 1-Hour 0.52	0.5 5 45,041	CREG RfC Intermediate STEL ceiling
Benzene MW = 78.11	0.00321		0.258	Annual 0.0022 24-Hour 0.03 1-Hour 0.31	0.1 13 160	CREG Intermediate EMEG Acute EMEG
Formaldehyde MW = 30.03	0.0588		0.12	Annual 0.001 24-Hour 0.014 1-Hour 0.15	10 0.08 37 49	Chronic EMEG CREG Intermediate EMEG Acute EMEG
Arsenic	2.18E-4		4.96E-4	Annual 4.2E-6 24-Hour 0.59E-4 1-Hour 6.0E-4	200E-6 43E-4	CREG Unit Risk – Acute
Beryllium	1.68E-5	Annual 0.14E-6 24-Hour 2E-6 1-Hour 20E-6	1.65E-5		400E-6 20,000E-6 2400E-6	CREG RfC Intermediate Unit Risk - Acute
Cadmium	8.55E-4		1.8E-3	Annual 15.2E-6 24-Hour 0.2E-3 1-Hour 2.2E-3	600E-6 1.8E-3	CREG Unit Risk - Acute
Chromium	8.98E-4		12.2E-4	Annual 10.3E-6 24-Hour 1.4E-4 1-Hour 14.9E-4	Assume all Cr is Cr+6	Compare to Cr+6 values below
Chromium 6	NA		NA	Annual 10.3E-6 24-Hour 1.4E-4 1-Hour 14.9E-4	80E-6 1 0.1 0.012	CREG Intermediate EMEG RfC Intermediate Unit Risk
Cobalt	5.44E-4	Annual 4.6E-6 1-Hour 6.6E-4	2.31E-4		100,000E-6 20	Chronic EMEG TWA
Lead	1.26E-3		2.14E-3	Annual 18E-6 1-Hour 2.6E-3	1.5	NAAQS quarterly
Manganese	7.71E-3		9.05E-3	Annual 76E-6 1-Hour 0.011	0.04 0.05	Chronic EMEG RfC Intermediate
Mercury	7.09E-3		7.27E-3	Annual 61E-6 1-Hour 0.0089	0.2 0.3	Chronic EMEG RfC Intermediate
Nickel	1.08E-3		1.34E-3	Annual 11E-6 1-Hour 0.0016	0.2 100-1500	Chronic EMEG TWA varies w/ cpd

* Ground level concentrations were calculated for the highest stack concentration for each chemical in any stack sample without regard to whether tires were being burned.

† NOx, SOx, and carbon monoxide values in Table 2 are from continuous emissions monitors. Only rolling averages were reported; maximum values were not available.

Data Sources: ACGIH 2002; ATSDR 2003; Dunmire 2003; Klingensmith 2003.

Appendix III – Emission Profile of Purdue Emissions Test

Item Measured	Baseline (lbs/hr)	5% whole tires (lbs/hr)
Max Operating Rate	200,000 lbs steam/hr	200,000 lbs steam/hr
Av. Operating Rate	181,000 lbs steam/hr	182,500 lbs steam/hr
PM Total	29.91	29.89
PM Filterable	28.03	27.74
PM Condensible	1.88	2.14
Opacity	8.00%	15.30%
SO_2	797.5	728
NO_X	128.9	136.8
CO	9.69	6.12
Dioxin/furan	0.0000991	0.000134
VOC's	0.72	0.145
HCl	1.52	2.35
HF	0.434	0.489
Antimony	< 0.001152	0.003286
Arsenic	0.0122	0.0566
Barium	0.00044	0.00156
Beryllium	0.0004	0.00155
Cadmium	0.000125	0.00051
Chromium	0.002092	0.0085
Aluminum	0.1338	1.608
Lead	0.018	0.04326
Manganese	0.106	0.0961
Mercury	0.001058	0.001
Nickel	0.0099	0.031
Selenium	0.0268	0.01903
Thallium	0.000702	0.00353
Zinc	0.12081	5.26
Calcium	0.02359	0.08996
Cobalt	0.002237	0.009531
Copper	0.007376	0.02967
Indium	0.001156	0.001
Molybdenum	0.003209	0.003722
Tellurium	<0.00204	0.004106
Tin	<0.003059	<0.003004
Tungsten	<0.003059	<0.003004
Uranium	<0.03059	<0.030044
Vanadium	0.001812	0.01249

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