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A Life-Cycle Inventory-Based Comparison of an RDX- Based and a TNAZ-Based GBU-24 Munition

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A Life-Cycle Inventory-based Comparison of an RDX-Based and a TNAZ-Based GBU-24 Munition

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ABSTRACT

U.S. Department of Defense (DoD) policy has elevated environmental considerations to an equivalent level of importance with cost and performance. Thus, with sponsorship from the Strategic Environmental Research and Development Program (SERDP), the DoD, U.S. Department of Energy (DOE), and U.S. Environmental Protection Agency (EPA) have cooperated in a program to develop technologies for clean production of propellants, energetics, and pyrotechnic (PEP) materials. Since the PEP program framework is strongly oriented around life-cycle assessment (LCA), a baseline life cycle inventory (LCI) of the guided bomb unit-24 (GBU-24) made with RDX explosives was conducted prior to this study in order to demonstrate the LCA approach.

The primary goals of this project were to develop and demonstrate the use of LCA as a means of comparing alternative PEP materials. A secondary goal was to produce an LCI for both the RDX-based and TNAZ-based munitions so that further work on improving the environmental footprint might take place.

In summary, based on a "less is best" comparison across a broad range of comparators, such as amount of listed (Federally regulated) waste or total energy consumption, the RDX-system appears to currently offer the least environmental dis-benefits. If some qualitative adjustments are made in the LCI to account for data quality, the RDX-based GBU-24 is still less environmentally harmful, but the gap between the systems is closed.

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Acronyms and Abbreviations

AHP	Analytical Hierarchy Process
AIRS	Aerometric Information Retrieval System
AIRS EXEC	AIRS Executive
AP	Acidification potential ("acid rain")
BCF	bio-concentration factor
BOD	biochemical oxygen demand
CAA	Clean Air Act
CIS	Chemical Information Systems
COCO	contractor-owned/contractor-operated
COD	chemical oxygen demand
CWA	Clean Water Act
DoD	Department of Defense
DOE	Department of Energy
EC	Expert Choice™
EIA	DOE's Energy Information Administration
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
GBU-24	Guided Bomb Unit (Earth penetrator bomb; Navy version is B/B)
GOCO	government-owned/contractor-operated
GWP	global warming potential
HAP	hazardous air pollutant
HSAAP	Holston Army Ammunition Plant
HV	hazard value
IARC	International Agency for Research on Cancer
IPPD	integrate product and process development
ISO	International Organization of Standards
LCA	life-cycle assessment
LCI	life-cycle inventory
LCIA	life-cycle impact assessment
LCImA	life-cycle improvements assessment
MCAAP	McAlester Army Ammunition Plant
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NSWC	Naval Surface Warfare Center
ODP	Ozone Depletion potential
PCB	polychlorinated biphenals
PCS	permit compliance system
PEP	propellants, energetics, and pyrotechnics
PM10	particulate <10 microns aerodynamic diameter
POCP	photochemical oxidant creation potential ("smog")
QSAR	quantitative structure activity relationship
RCRA	Resource Conservation and Recovery Act

R&D	research and development
RDX	trimethylenetrinitramine explosive
SAR	structure activity relationship
SETAC	Society of Environmental Toxicology and Chemistry
SERDP	Strategic Environmental Research and Development Program
TDS	total dissolved solids
TPY	tons per year
TRI	toxic release inventory
TSCA	Toxic Substance Control Act
TSS	total suspended solids
VOC	volatile organic compound
WOE	weight-of-evidence

1.0 Introduction

While the greening of weaponry may seem contradictory, it is not. Much of the weaponry prepared for the U.S. Department of Defense (DoD), especially larger items, is never consumed in the act of warfare, but is only a deterrent. As long as it remains a deterrent, preparing, maintaining, and disposing of (old or out-of-date) weaponry are acts through which humans and the environment interact with the weaponry and the resulting input or output streams. These activities, or the resulting emissions and consumption, are an argument for the greening of weaponry. In fact, current DoD policy has elevated environmental considerations to an equivalent level of importance with cost and performance (Perry, 1994).

The Strategic Environmental Research and Development Program (SERDP) is a cooperative effort between the DoD and the Department of Energy (DOE) to investigate Clean Agile Manufacturing of Propellants, Explosives, and Pyrotechnics. Coupled with DoD policy initiatives (outlined in 1994 by then Secretary Perry), the SERDP activity seeks to investigate and develop new and improved materials and processes that are intended to provide pollution prevention benefits of 50 percent to 90 percent reduction in Federally-regulated wastes. Within the diagnostic and analytical component of this effort, several evaluative tools and techniques are being evaluated, adapted for use in the DoD setting, and eventually exported to the weapons system design and development teams for application as routine procedures in system acquisition.

With these goals in mind and in cooperation with the US EPA through the Life Cycle Engineering and Design Project, SERDP set out to investigate the usefulness of life cycle assessment (LCA) methods to assess the greenness of a weapon system through a demonstration project. The goals of this study are two-fold. One, the application of LCA to provide a key part of the information basis for improvements is to be demonstrated. Two, the general approach to life-cycle improvement assessment, as adapted to DoD applications, is to be developed and ultimately disseminated to the users. The munition chosen for the study was the GBU-24 Earth-Penetrating Bomb.

Reasons for choosing this munition include: 1) substitutes for the RDX-based explosive core are currently being investigated; trinitroazetidine (TNAZ) is one compound being considered, 2) other complementary manufacturing improvements are under development, and 3) Los Alamos National Laboratory has previously prepared an extensive systems model of the manufacturing operations and environmental profile for the RDX-based GBU-24.

Life Cycle Assessment (LCA) is a holistic method for examining the impact of a product or process on the environment. In an LCA the act of producing or processing is linked mathematically with activities occurring upstream (prior to the process of interest) and downstream (after the product of interest). These mathematical links allow the analyst to relate the contribution of the product or process, as well as each upstream or downstream contributing or supporting process, to the net system emissions or consumption resulting from the act of producing and using a product or process. The International Standards Organization (ISO) has developed two standards governing LCA. Standard 14040 describes the general principles and framework of LCA and Standard 14041 provides more detailed information on goal and scope definition and inventory analysis.

An LCA typically consists of several distinct phases. The first phase is Goals, Scope, and Boundary Definition. Here the purpose(s), objective(s), or question(s) to be answered through conduct of the LCA are defined, as is the extent of the system to be modeled — what processes are or are not intended to be included, i.e., the system boundary. According to the ISO standard, in defining the scope, the following items shall be considered and clearly described:

- Function
- Systems to be studied
- Allocation procedures
- Assumptions
- Initial data quality requirements
- Type and format of study report
- Functional unit
- System boundaries

-
- Data requirements
 - Limitations
 - Type of critical review (if any).

The second phase is the Life Cycle Inventory (LCI), which is the tabulation of the emissions and consumption associated with a product or process. Life Cycle Impact Assessment (LCIA) is the third phase. Here emissions or consumption terms are linked to environmental problems such as Global Warming Potential, Resource Depletion, or Human Health. The final phase is Interpretation. During this phase, the systems data are analyzed to determine which materials and processes contribute most to the results and to identify aspects in which the baseline and alternative systems are or are not discernibly different. These phases are interrelated and iterative. Life Cycle Improvements Assessment (LCImA) is but one of a number of uses to which the interpretation might be directed. Here the results of the LCI and LCIA are interpreted and qualitative evaluations of potential environmental improvements are identified.

For this improvement assessment, only the the LCI stage was conducted. These activities were conducted in accord with the U.S. EPA technical guidance manual (1993) for LCI studies. A parallel study (U.S. EPA, 1997b) on the life cycle impacts associated with the RDX-based GBU-24 system was used as a reference in estimating the impacts associated with the TNAZ-based GBU-24. The inventory data for the RDX-based GBU-24 are identical for each study.

2.0 Goals, Scope and Boundary Definition

Goal Definition

During the period 1993-95 the baseline resource use and pollution burdens for the life cycle of the GBU 24 B/B earth penetrator bomb unit were examined using a combination of primary data collected from the production sites and secondary-modeled data and literature information for commercial operations such as steel and ammonia production. This study was conducted by the Los Alamos National Laboratory. This information showed certain pollutional characteristics associated with both the batch production of the RDX and aluminum fill used in the GBU24 and the environmental burdens associated with on-site- and off-site-produced electricity and steam. Several alternative materials and processes are in various stages of development and could function as either replacement components, alternative processing technologies, or substitute materials.

The goal of this life cycle inventory study is to compare one such alternative energetic material, trinitroazetidine (TNAZ), with the baseline RDX (royal demolition explosive) energetic material. Although the primary implementation of this goal involved the development of data modules pertaining to TNAZ production, certain other changes, necessitated by the different physical and chemical properties of TNAZ, were required to be introduced into the baseline. These other differences are summarized below and discussed in greater detail further in the body of the inventory report.

TNAZ, like RDX, is compounded into the explosive mix and fill material (CXM7 and PBXN109 in the case of RDX) by blending it with other ingredients. It is likely that in actual production the blend would be tailored to the specific characteristics of TNAZ. However, for purposes of this inventory, which was configured to allow examination of TNAZ as a "drop-in" replacement for RDX, the fill material selected was an 80:20 mixture of TNAZ and aluminum, identical to that used in the current GBU24.

Production of TNAZ uses very different starting

materials than RDX. Hence, the upstream operations were characterized on the basis of commercial production activities and secondary data sources. Depending on the amounts produced, actual production may determine that certain of the precursors could be produced by government-owned, contractor-operated (GOCO) facilities. Such GOCO facilities could be located at the existing sites for production of RDX-based munitions or at a greenfield site.

- In the original baseline inventory, the time distribution of resource consumption and emissions was based on assumptions about the peacetime production rates and the expected operational obsolescence of the stockpile of GBU24. Since no logistics setting has been uniquely defined for the TNAZ-based item, it was assumed that the operational deployment activities would be performed similarly except for the actual steps in demilitarization efforts that are specific to the physical properties of TNAZ.
- TNAZ has never been produced on a commercial scale. Therefore, it is impossible to obtain resource use and emissions information from actual full-scale operations. Instead the data developed from smaller scale (1 kg to 1,000 kg) syntheses was scaled to approximately commercial engineering operations through use of process simulation and thermodynamic computation models to assess ancillary operational requirements.
- Due to data problems with a subcontractor, not all of the data detail specified in the preliminary goal definition and scoping were obtained. This necessitated the assumption that certain process energy requirements for a TNAZ-filled GBU would be identical to those for the current GBU. This is unlikely to be entirely the case; however, given the data deficiency no other pathway was available.

Scope Definition

The intended scope of this study is the inventory

analysis of TNAZ as a drop-in replacement energetic fill material for RDX in a GBU-type end item. The inventory covers the cradle-to-grave activities of the alternative system in a manner similar to that of the baseline inventory. Specifically omitted are wartime deployment and stockpile replenishment and shipboard readiness activities. Also, in keeping with the boundaries of the original inventory, the resource use and emissions from RD&D activities during system development were excluded. In fact, these activities, particularly laboratory scale syntheses using alternative chemistries, engineering scale up trials, and qualification testing all have the potential to be contributory to the life-cycle profile. However, in the interest of showing the current profile for an "as-deployed" end item, these early stage contributions were omitted. All other operations from initial raw materials manufacturing to ultimate demilitarization were included in the system boundaries.

This study was conceived as including only an inventory analysis. Although an equivalency-based life-cycle impact assessment has been produced for the RDX-based item, resources did not permit a parallel effort for the TNAZ case study. Therefore, data collection and associated quality goals were specified for an inventory analysis. No external, third party critical review was identified as needed for the study. However, peer review was provided by the sponsoring organizations directly (U.S. EPA) and indirectly (U.S. Army).

The report format was designed to communicate clearly with the intended users. As noted in the introduction, there are two groups of users within the acquisition team — the process and system designers and the weapons system program managers and supervisory staff. In the former group, it is most important to illustrate the details of which activity steps are contributory to the overall environmental burdens. In the latter group, it is important to have the ability to compare the two different fill alternatives with respect to DOD-controlled versus commercial sector activity and to distinguish wastes that "count" towards the pollution prevention reduction goal (i.e., are listed wastes in RCRA, the Clean Water Act, or other legislation from the total environmental burdens), e.g., carbon dioxide contributions to global warming. These latter wastes may be used to further express general improvements in the overall environmental profile, but do not address achievement of the stated P2 goal.

Boundary Definition

For each system, all activities from acquisition of raw materials (geologic and biotic resources) through ultimate (peace-time) disposal were included. Excepted from the system were weapon system maintenance

and/or preparatory activities, for example, periodic maintenance and calibration while deployed and any military use-readiness activities. Also excepted, as noted above, were research and development activities, and testing and deployment activities.

Primary materials common to both systems include iron ore, limestone, and coal for the bomb body and crude oil and natural gas as feedstocks for chemical synthesis or as fuels. Demilitarization was different for each system. Both systems also require salt and a source of nitrogen for use in upstream synthesis operations. The systems differ in the modes of acceptable demilitarization. Physical removal of the RDX followed by burning, to reduce volume, is the disposal method for RDX. Melt-out of TNAZ for recycle into other munitions is the method modeled. In each case, the bomb body is recycled via the scrap steel recycling infrastructure. Although it may be possible to reuse the bomb body with only minor refurbishment in the case of TNAZ, this operation was not modeled.

3.0 System and Inventory Module Descriptions

The GBU-24 is an earth penetrator bomb equipped with a laser guidance package designed to penetrate up to 6 feet of reinforced concrete. As shown in Figure 3-1, the assembled item consists of several component and subcomponent parts. The BLU-109 bomb body is the largest physical component and contributes the majority of the material mass to the system. The other components listed were not included because they are minor in comparison and are readily reused in any event. Within the BLU-109, the bomb case itself is the largest source of material (approximately 70 percent of the total weight) and efforts are underway to evaluate ways to reduce pollution from its manufacture through recycling of the steel. Approximately 27 percent of the total comes from the explosive fill. The PBXN-109 is a blend of four components: CXM-7 explosive mix, aluminum powder, thermoset plastic binder, and miscellaneous other blending and forming agents. About 3 percent of the mass is contributed by thermal insulation applied to the bomb exterior and asphalt interior liner.

The work flow representation of the RDX-based GBU-24 life cycle is illustrated in Figure 3-2. Raw materials are sourced for the energetic materials production from commercial commodity chemical producers. The synthesis of RDX, together with the coating and blending to manufacture CXM-7, is provided by Holston Army Ammunition Plant (HSAAP) in Kingston, TN. The CXM-7 is then shipped to McAlester Army Ammunition Plant (MCAAP) in McAlester, OK. Load/assemble/pack (L/A/P) operations are performed at MCAAP, which includes blending the CXM-7 with aluminum and other additives to produce the plastic-bonded explosive used for the GBU-24. The steel bomb bodies are also shipped to MCAAP from a commercial producer (National Forge).

For the TNAZ-based munition it was assumed that a similar arrangement would be maintained. Precursor materials to the explosives are purchased from various suppliers. Munition disassembly and explosive destruction or reclamation occurs at Indian Head Naval Surface Warfare Center (IHNSWC). Currently RDX is burned

and the resulting ash disposed of in a landfill. One advantage of TNAZ is that it can be reclaimed and reused a number of times. The reclamation operation was also assumed to occur at Indian Head. Each system requires transport of materials or munitions, and consumes an amount of electricity generated off-site.

For the two systems, the L/A/P operations at McAlester were assumed to be almost identical in that TNAZ was assumed to be a true "drop-in" replacement for RDX. This is not exactly the case since TNAZ has a greater energy density and, thus, needs some additional filler to increase the mass and volume of TNAZ-based explosive material in the GBU-24 in order to maintain its flight characteristics.

One other point to consider is the state of development of each of the two systems. The RDX-based munition has been produced for a number of years, hence optimization of the system with regard to yield and energy efficiency is near maximum. The TNAZ-based system is still in the lab scale/pilot scale developmental stage. While much optimization has taken place (more than an order of magnitude reduction in total waste per pound of TNAZ produced was achieved between 1993 and 1996 alone), it is thought that more will occur, especially as the system is scaled up to production quantities. The TNAZ system modeled in this LCI is a hybrid of lab and/or pilot scale developments with some potential, and highly probable, modifications to increase yield or energy efficiency, or change the input resource to those thought to be cause less environmental harm.

RDX-Based System

A baseline inventory (LCI) of the current GBU-24 earth penetrator bomb was conducted during 1993 and 1994 (the data basis was 1992 operations). That effort attempted to adhere very closely to the LCI methodology described in Society of Environmental Toxicology and Chemistry (SETAC) and U.S. EPA technical guideline publications (U.S. EPA, 1993). Preliminary results of that analysis have been reported in several forums and publications (Ostic, 1994; Brown, 1995; Newman and Hardy, 1995) and are briefly

summarized below. Numerous organizations supplied information for the baseline effort including the following.

- Commercial Raw Materials Production, Fuels Acquisition, and Electric Power Generation: Battelle Columbus
- Intermediate/Fill Materials Production and L/A/P Operations: Holston and McAlester Army Ammunition Plants
- Use/Maintenance and Demil Operations: Naval Surface Warfare Center, and Coordination of Inventory Data Assembly: Engineering Systems Analysis Department, Los Alamos National Laboratory.

- Toxics Release Inventory (TRI)
- Resource Conservation and Recovery Act (RCRA).

Assembly and validation of the data, together with the modeling of the system resource consumption and environmental burdens, was performed by the Technology Modeling and Analysis Group at LANL. The environmental emissions and energy and resource consumption output from this model was provided to Battelle.

Modeling of the GBU-specific manufacturing operations was performed in considerably greater detail than for the commercial sector activities. This was done for several reasons, not the least of which was the fact that the span of control of DoD for influencing such major industrial activities as steel and ammonia manufacture is limited. Table 1 illustrates the specific activities and process streams included in the LANL LCI model.

Battelle tabulated the inventory data provided by LANL in two dimensions. The first dimension was life cycle stage as Precursor production, HSAAP operations, MCAAP operations, IHNSWC operations, Transportation, Waste Management, and Electricity production, in order to relate emissions to the scope of control of the involved entities. The second dimension was regulatory status: Listed or Non-listed. Listed wastes are those explicitly mentioned in any of the following Federal environmental regulations, and are those to which the pollution prevention goals mentioned above are directed.

- Comprehensive Environmental Restoration, Compensation and Liability Act (CERCLA/Superfund)
- Toxic Substances Control Act (TOSCA)
- Clean Water Act (CWA)
- Clean Air Act and Amendments (CAAA)
- Superfund Amendments and Reauthorization Act (SARA)

GBU-24 is a Conventional Explosive Earth Penetrator Weapon

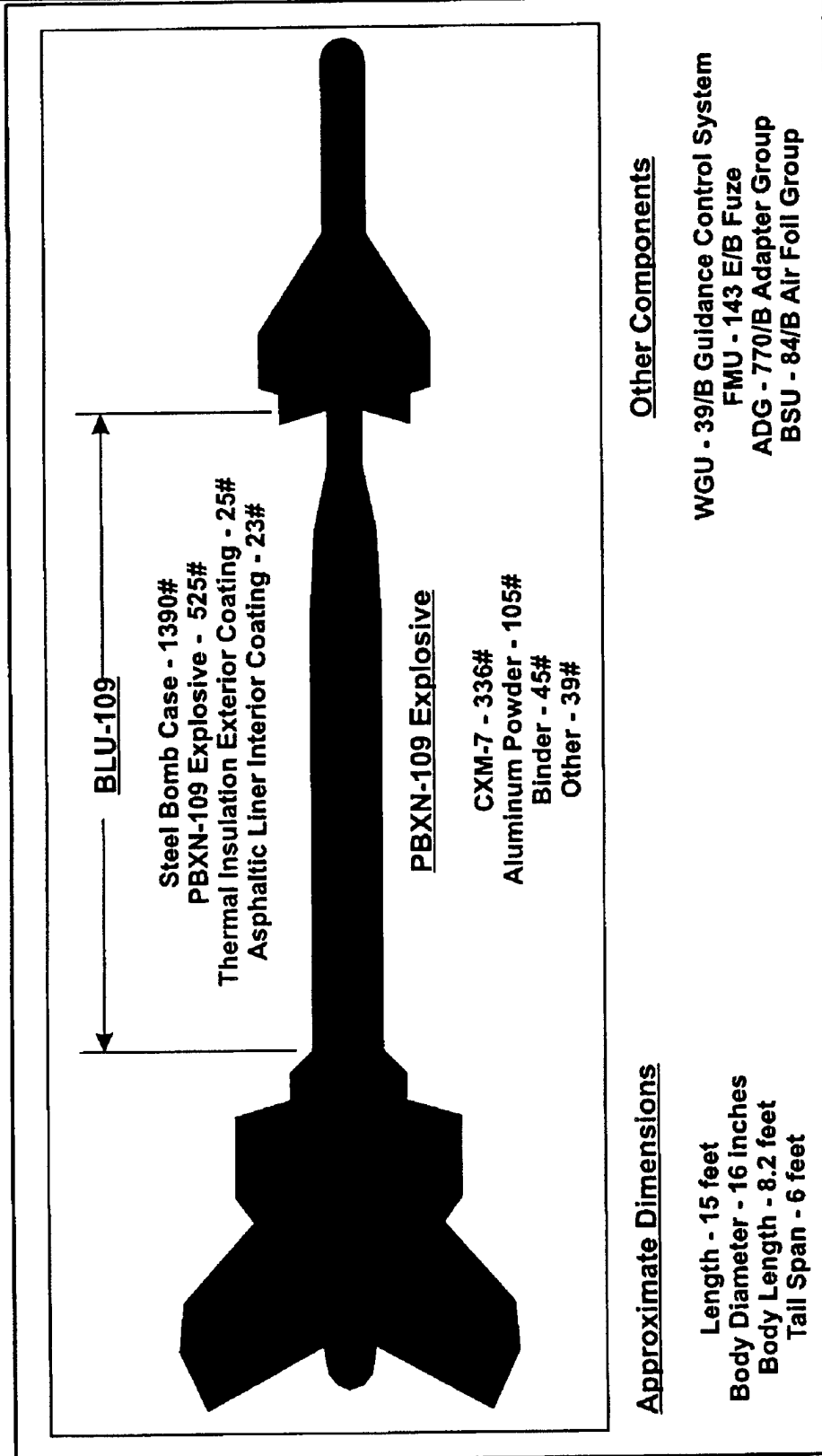
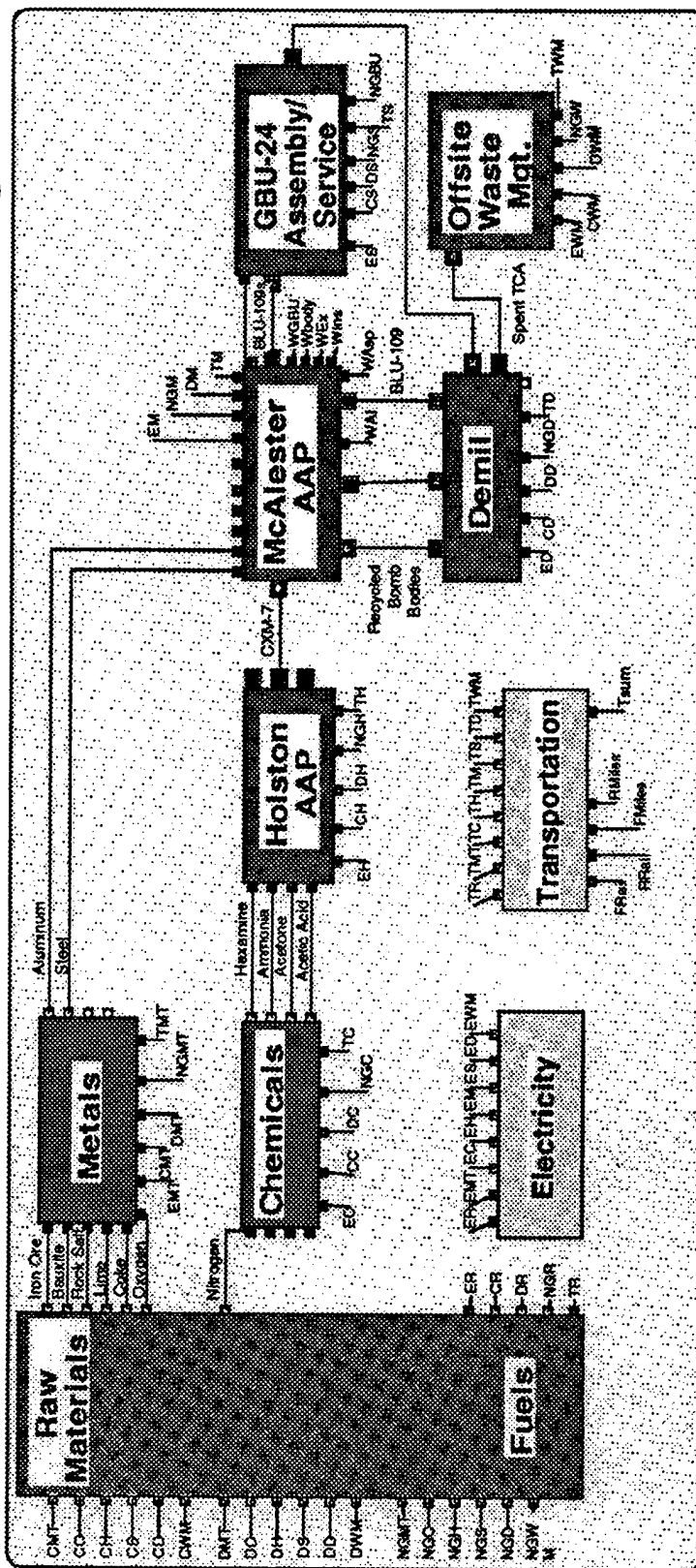


Figure 3-1. GBU-24: A conventional explosive earth penetrator (the functional unit for the LCA is the bomb body called BLU-109).



The diagram consists of two main rectangular boxes, one on the left and one on the right, both with a textured background. The left box is titled "Pollution Burdens" and contains three smaller boxes stacked vertically: "Solid Waste", "Liquid Waste", and "Gaseous Waste". The right box is titled "Energy Requirements" and contains three smaller boxes stacked vertically: "Electrical", "Coal", and "Diesel Products". To the right of the "Diesel Products" box is another box labeled "Natural Gas".

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graph LR
    subgraph Pollution_Burdens [Pollution Burdens]
        SW[Solid Waste]
        LW[Liquid Waste]
        GW[Gaseous Waste]
    end
    subgraph Energy_Requirements [Energy Requirements]
        E[Electrical]
        C[Coal]
        DP[Diesel Products]
    end
    NG[Natural Gas]
  
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Table 3-1. Summary of Data Included in LANL RDX-based GBU-24 Life Cycle Inventory

Process or Activity	Consumption			Emissions Water	Solid Waste
	Resources	Energy	Air		
Geologic and Biotic Resource Extraction					
Bauxite	Included	Included	Included	Included	Included
Coal	Included	Included	Included	Included	Included
Iron Ore	Included	Included	Included	Included	Included
Limestone		Included			
Natural Gas	Included	Included	Included	Included	Included
Petroleum	Included	Included	Included	Included	Included
Intermediate Materials Manufacture					
Acetic Acid	Included	Included	Included	Included	
Acetone	Included	Included	Included	Included	Included
Aluminum	Included	Included	Included	Included	Included
Ammonia	Included	Included	Included	Included	
Coke		Included			
Cyclohexanone					
Diethyl adipate (DOA)					
Formaldehyde	Included	Included	Included		
Hexamine	Included	Included			Included
Nitric acid	Included	Included	Included	Included	
Nitrogen		Included			
Oxygen		Included			
Propyl acetate					
Steel	Included	Included	Included		Included
Steel Forging	Included	Included			
Trichloroethane					
Triethyl phosphate					
Holsten AAP					
Acetic acid Production	Included	Included	Included	Included	Included
Acetic anhydride Concentration	Included	Included	Included	Included	Included
Area A Steam Plant	Included	Included	Included	Included	Included
Explosives Plant	Included	Included	Included	Included	Included
Nitric acid Production	Included	Included	Included	Included	
Spent acid Recovery	Included	Included	Included	Included	
Nitric acid Concentration	Included	Included	Included	Included	
Nitric acid - Ammonium nitrate	Included	Included	Included	Included	
Production					
Industrial Wastewater	Included	Included		Included	Included
Treatment Plant					
Filtered Water Production					
Burning Ground					
Incinerator					
McAlester AAP					
Inert Preparation	Included	Included	Included		Included
Receiving	Included	Included			
Mixing	Included	Included	Included		Included
Casting	Included	Included	Included	Included	Included
Bomb Seal	Included	Included		Included	Included
Final Assembly	Included	Included			
Radiography	Included	Included			
Chemical Laboratory	Included	Included	Included		Included
Boiler	Included	Included	Included		
Demilitarization					
Disassembly		Included			
Water Jet Washout	Included	Included		Included	Included
Solvent Soak	Included	Included		Included	Included
Burning Ground		Included	Included		Included
Water Treatment	Included				
Off-site Electricity Generation					
Coal-fired Plant	Included	Included	Included		Included
Diesel-fired Plant	Included	Included	Included		
Natural gas-fired Plant	Included	Included	Included		
National Grid	Included	Included	Included	Included	Included
Transportation					
Transportation	Included	Included	Included	Included	Included

TNAZ-based System

The approach to modeling the life cycle of the TNAZ-based munition was a straight-forward replacement of the appropriate processes and segments of the RDX-based system. No work had been done on modeling the TNAZ-based system, but the LANL computational framework and engine are modular so that appropriate TNAZ specific pieces could be substituted. Battelle undertook the generation of modules for precursors to TNAZ production, along with modules for demilitarization including recycling of TNAZ. This modeling effort entailed preparing process characterizations and mass balances for each needed module. Battelle subcontracted with LANL to integrate the new modules into the existing computational framework to make adjustments to the model for changes in operations and emissions at Holston and McAlester that would result upon the substitution of TNAZ into the GBU, and to provide results for a number of defined scenarios. The task of calculating process energy requirements and

government-owned facility energy infrastructure changes necessary to support TNAZ manufacture and use was also subcontracted to LANL.

The modules prepared by Battelle included formaldehyde, NIB-glycerol, di-isopropylazodicarboxylate, triphenyl phosphine, acetic anhydride, tert-butylamine, sodium hydroxide, hydrochloric acid, hydrogen peroxide, isopropanol, 2-butanone (methyl ethyl ketone), sodium nitrite, potassium ferrocyanide, sodium persulfate, methyl tert-butyl ether, ferrous chloride, nitric acid, ammonium nitrate, ethanol, acetonitrile, nitrogen, deionized water, Dow 2210 antifoaming agent, and melt out of TNAZ from decommissioned munitions. Data for these modules was taken from the LANL work on RDX and from other LCIs. Some modules were developed from first principles of chemical engineering. A complete listing of calculations and data sources is given in Appendix D, while data sources and brief descriptions are given in Table 3-2.

Table 3-2. Summary of TNAZ-Based LCI Modules Prepared by Battelle

Module	Data Sources	Notes
Formaldehyde Methanol	Brown, Hamel and Hedman, 1985 Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S. EPA, 1985; Kirk-Othmer, 1991; CRC Press, 1986	Production of formaldehyde from methanol. Engineering calculations for methanol production as part of acetic acid production.
Acetic acid Manufactured gas or Synthesis gas Nitroethane	Lowenheim and Moran, 1975 Kirk-Othmer, 1964 Kirk-Othmer, 1978; W.R. Grace Co., 1992	Production of acetic acid from methanol. Production of synthesis gas from coal. Co-production of nitro compounds: nitroethane, nitromethane, nitropropane, from nitrogen and light hydrocarbons.
Nitric acid and Ammonium nitrate	Holston Defense Corporation	Co-production of nitric acid and ammonium nitrate at Holston AAP.
Diisopropylidazodicarboxylate	McGraw Hill, 1984; U.S. EPA, 1985; CRC Press, 1986.	Engineering calculations of emissions and energy and resource consumption from DIAD production.
Phosgene	Lowenstein and Moran, 1975; McGraw Hill, 1984; CRC Press, 1985; U. S. EPA, 1985; SRI, 1993	Engineering calculation of emissions and energy and resource consumption for phosgene production.
Ammonia	U.S. EPA, 1985; U.S. DOE, 1994; U.S. EPA, 1995; U.S. DOE, 1993	Production of fertilizer quality ammonia.
Sodium hydroxide	SimaPro 3.0, 1994	Co-production of sodium hydroxide, chlorine and hydrogen via electrolysis of brine.
Sulfuric acid	U.S. EPA, 1995; Fertilizer Institute, 1982	Production of sulfuric acid via the phosphate wet method.
Monochlorobenzene	Lowenheim and Moran, 1974; McGraw Hill, 1984; U.S. EPA, 1985; Kirk-Othmer, 1964; U.S. ITC, 1994	Engineering calculation of emissions and resource and energy consumption for monochlorobenzene production.
Benzene Isopropanol	SimaPro 3.0, 1994 Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S. EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1985	European production of technical grade benzene. Engineering calculation of emissions and resource and energy consumption from isopropanol production.
Propylene Phosphorus trichloride	SimaPro 3.0	European production of monomer quality propylene. Engineering calculations of emissions and energy and resource consumption for phosphorus trichloride production.
Acetic anhydride Acetic acid	Holston Defense Corporation Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S. EPA, 1985; Kirk-Othmer, 1964; CRC Press, 1986	Production of acetic anhydride at Holston AAP. Engineering calculation of emissions and resource and energy consumption for acetic acid production.
Methyl Ethyl Ketone	Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S. EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1986	Engineering calculation of emissions and resource and energy consumption for MEK production.
Butylene	SimaPro 3.0, 1994	European production of monomer quality butylene.

Module	Data Sources	Notes
Methyl tert-Butyl Ether	Lowenheim and Moran, 1975; Mc Graw Hill, 1985; U.S. EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1986	Engineering calculation of emissions and resource and energy consumption during MTBE production.
Ethanol (via Fermentation from Corn Sugars)	Numerous	Production and harvesting of corn. Transportation of corn to processing center. Milling of corn to separate sugars and starches from fiber.
Acetonitrile	Lowenheim and Moran, 1975; Mc Graw Hill, 1985; U.S. EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1986	Engineering calculation of emissions and resource and energy consumption during co-production of acetonitrile and acrylonitrile.
Demilitarization		Engineering calculations of emissions and resource and energy consumption during demilitarization.

A number of assumptions were made for the TNAZ - based system LCI. First, energy consumption would be similar for both the RDX-based and TNAZ-based systems so that the RDX-based energy consumption information could be used in the TNAZ-based system LCI. Second, the transportation infrastructures for the two systems were identical. Given that manufacturing operations have not been sited for the processes this appears to be a reasonable approach. If direct reuse of the bomb body proves feasible then transportation emissions and energy consumption should decrease for the TNAZ-based GBU. The third assumption was that the electricity generation emissions were also identical in the two systems. In part, these assumptions were necessary to complete the LCI because LANL was not able to provide the results of the TNAZ-based modeling in sufficient detail to allow TNAZ-specific substitutions to be developed and incorporated into the LCI and verified.

4.0 Results

The detailed life cycle inventories are presented in Appendices A and B for the RDX-based and TNAZ-based systems, respectively. The following tables and figures summarize and compare the results presented in Appendices A and B. For most of the results presented in the tables the wastewater emitted during production of the TNAZ-based GBU-24 has been intentionally omitted. Since *no* wastewater emission is listed for the RDX-based system the description of the wastes for the two systems is more comparable when this omission from the RDX-based system emissions is compensated for by ignoring wastewater emissions from the TNAZ-based system. The result is a comparison of the mass of contamination of the wastewater.

Table 4-1 lists Total Emissions from each of the two systems. The amounts of listed and non-listed wastes are also given. For both Total Emissions and Listed Emissions the RDX-based munition has significantly lower emissions. There is no discernable difference among the systems for Non-Listed Emissions. The results are presented in Figure 4-1.

Table 4-1. Total Emissions from Systems (in pounds per GBU-24)

Emission	RDX-based GBU-24	TNAZ-based GBU-24
Listed	1,158	20,733
Non-Listed	30,837	29,547 ⁽¹⁾
Total	31,995	50,280

⁽¹⁾ Less wastewater discharge of 11,654,826 lb.

Emissions by environmental compartment also tend to favor the RDX-based system (see Table 4-2 and Figure 4-2). The exception being Air Emissions where no discernable difference exists between the systems.

Table 4-2. Emissions from Systems by Environmental Compartment (in pounds per GBU-24)

Compartment	RDX-based GBU-24	TNAZ-based GBU-24
Air Emissions	26,945	27,072
Water Emissions	354	9,176 ⁽¹⁾
Solid Wastes	4,697	14,033

⁽¹⁾ Less wastewater discharge of 11,654,826 lb.

Tables 4-3 and 4-4 and Figures 4-3 and 4-4 present the results for Listed and Non-Listed Emissions by point of origin. Emissions for Transportation, Waste Management, and Off-site Electricity Production were identical for the two systems since the RDX-based system data was used for the TNAZ-based system. The RDX-based system has lower emissions of Listed Wastes during Precursor Production and at Military Facilities. Non-Listed Wastes emitted from Military Facilities are lower for the TNAZ-based system.

Table 4-3. Listed Emissions for Each System by Point of Origin (in pounds per GBU-24)

Point of Origin	RDX-based GBU-24	TNAZ-based GBU-24 ⁽¹⁾
Precursors Production	620	7,640
Military Facilities	364	12,919
Transportation	4	4
Waste Management	0	0
Off-site Electricity Production	169	169

⁽¹⁾ Less wastewater discharge of 11,654,826 lb.

Table 4-4. Non-Listed Emissions for Each System by Point of Origin (in pounds per GBU-24)

Point of Origin	RDX-based GBU-24	TNAZ-based GBU-24 ⁽¹⁾
Precursors Production	6,332	6,291
Military Facilities	7,934	6,685
Transportation	189	189
Waste Management	773	773
Off-site Electricity Production	15,609	15,609

⁽¹⁾ Less wastewater discharge of 11,654,826 lb.

Resource consumption is also much less for the RDX-based GBU-24 (see Table 4-5 and Figure 4-5). Again, however, there was an obvious omission from the results for the RDX-based system in that there was *no* water consumption. For the TNAZ-based GBU-24 water consumption amounts to almost 2.5 million pounds. The

values in the table and figure include this water consumption. (Geologic and Biotic Resources are raw materials extracted from or grown on the earth or oceans. Intermediate Materials are refined products that have not been traced back to geologic or biotic materials. For example, crude oil is a geologic resource, while gasoline is an intermediate material.)

Table 4-5. Resource Consumption by Systems (in pounds per GBU-24)

Resource	RDX-based GBU-24	TNAZ-based GBU-24
Geologic and Biotic Resources	20,133	6,372,692 ⁽¹⁾
Intermediate Materials	1,009	21,846

⁽¹⁾ Includes 2.5 million pounds of water consumed

Table 4-6 and Figure 4-6 illustrate the geologic and biotic resource consumption by stage. Figure 4-7 and Table 4-7 present the results for intermediate materials consumption. Again, data for Transportation, Waste Management, and Off-site Electricity Production are identical for the two systems. Differences in resource consumption are not discernable between the systems for any stage except for Precursor Production, where the RDX-based system is considerably lower. The RDX-based system is also lower for Intermediate Materials consumption for both Precursor Production and consumption at Military Facilities.

Table 4-6. Geologic and Biotic Resource Consumption by Stage (in lb per GBU-24)

Stage	RDX-based GBU-24	TNAZ-based GBU-24
Precursor Production	9,630	6,361,792
Military Facilities	4,178	4,575
Transportation	0	0
Waste Management	100	100
Off-site Electricity Generation	6,225	6,225

Table 4-7. Intermediate Materials Consumption by Stage (in lb per GBU-24)

Stage	RDX-based GBU-24	TNAZ-based GBU-24
Precursor Production	296	14,268
Military Facilities	713	7,578
Transportation	0	0
Waste Management	0	0
Off-site Electricity Generation	0	0

Energy consumption again is lower for the RDX-based GBU-24, by a wide margin (see Figure 10). Energy consumption (all energy sources considered) was 151 million Btus per GBU-24 for the RDX-based system and 1,954 million Btus per GBU-24 for the TNAZ-based system. For the RDX-based system it is 73.4 percent derived from coal and 19.8 percent derived from natural gas, with the balance being electricity or petroleum. Steam (fuel(s) unspecified) was the primary energy source for the TNAZ-based system at 88.4 percent. Nuclear energy (5.2 percent) and coal (3.8 percent) are the next biggest energy sources.

Table 4-8 and Figure 4-9 illustrate Energy consumption by stage. Again the same data were used for both systems for the Transportation, Waste Management, and Off-site Electricity Production stages. For the remaining stages, Precursor Production, and at Military Facilities, the RDX-based system consumes much less energy.

Table 4-8. Energy Consumption by Stage (in Mbtu per GBU-24)

Stage	RDX-based GBU-24	TNAZ-based GBU-24
Precursor Production	12	148
Military Facilities	61	1,728
Transportation	1	1
Waste Management	3	3
Off-site Electricity Production	73	73

Table 4-9 presents a summary of all of the comparisons made above. For each comparison, the system that was the most environmentally beneficial, judged as less is better, was indicated on the table with a '+'. A difference between the systems of 15 percent was used to judge which was better, i.e., the value for the TNAZ-based system had to be more than 15 percent higher or lower than the value for the RDX-based system in order for one of the systems to be judged better. If the values for the systems did not differ by more than 15 percent neither was judged to be better. The value of 15 percent was chosen based on the experience of the analyst. As a check on this choice a 10 percent margin was also used. The information in Table 4-9 does not change with a 10 percent margin. If the margin is changed to 20 percent, the outcome of one comparison changes. Instead of the TNAZ-based system being better for Non-Listed Military Facility Emissions, neither system is better.

The value chosen for the margin is a reflection of the perceived data quality. The higher the perceived quality of the data the lower the margin at which one believes comparable systems can be differentiated. Which is the

most correct value? Battelle recently completed a LCI on residential nylon carpet for the U.S. EPA (1997a) in which the propagation of error in an LCI was studied. What was found was that, for the carpet system, individual input parameters could be varied by as much as 20 percent with 95 percent of the output values varying by less than 13 percent. The TNAZ-based system LCI contains a large number of engineering

estimates for emissions and consumption simply because the system has not been scaled up and operated at full scale to allow measurements. While these are engineering estimates, they are not likely to vary by more than 20 percent from the true values. Therefore, the output is expected to vary on the order of 15 percent, as it did for the carpet LCI, thus the choice of a 15 percent margin.

Table 4-9. Life Cycle Inventory Summary Comparison

Comparator	RDX-based GBU-24	TNAZ-based GBU-24
Total Emissions	.	
Listed Emissions	.	
Non-Listed Emissions		
Air Emissions		
Wastewater Emissions	.	
Solid Wastes	.	
Listed Emissions - Precursor Production	.	
Listed Emissions - Military Facilities	.	
Listed Emissions - Transportation	.	
Listed Emissions - Waste Management		
Listed Emissions - Off-site Electricity Production		
Non-Listed Emissions - Precursor Production		
Non-Listed Emissions - Military Facilities		.
Non-Listed Emissions - Transportation		
Non-Listed Emissions - Waste Management		
Non-Listed Emissions - Off-site Electricity Production		
Total Resource Consumption	.	
Geologic and Biotic Resources	.	
Intermediate Materials	.	
Geologic and Biotic Resources - Precursor Production	.	
Geologic and Biotic Resources - Military Facilities		
Geologic and Biotic Resources - Transportation		
Geologic and Biotic Resources - Waste Management		
Geologic and Biotic Resources - Off-site Electricity Generation		
Intermediate Materials - Precursor Production	.	
Intermediate Materials - Military Facilities	.	
Intermediate Materials - Transportation		
Intermediate Materials - Waste Management		
Intermediate Materials - Off-site Electricity Generation		
Total Energy Consumption	.	
Energy Consumption - Precursor Production	.	
Energy Consumption - Military Facilities	.	
Energy Consumption - Transportation	.	
Energy Consumption - Waste Management		
Energy Consumption - Off-site Electricity Generation		

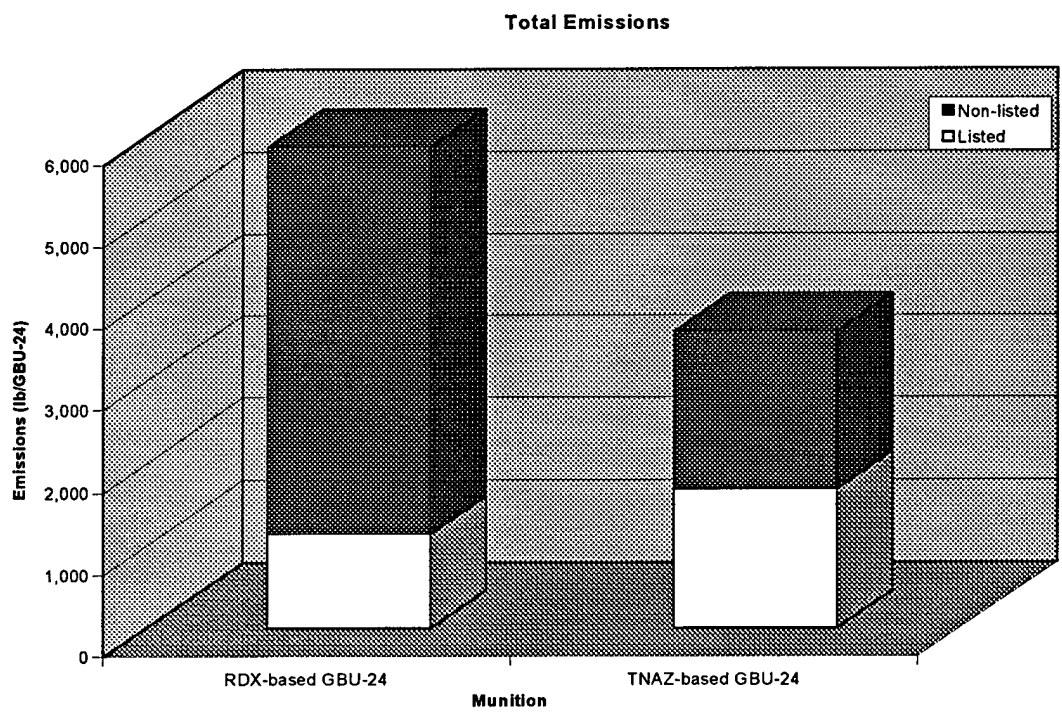


Figure 4-1. Total emissions.

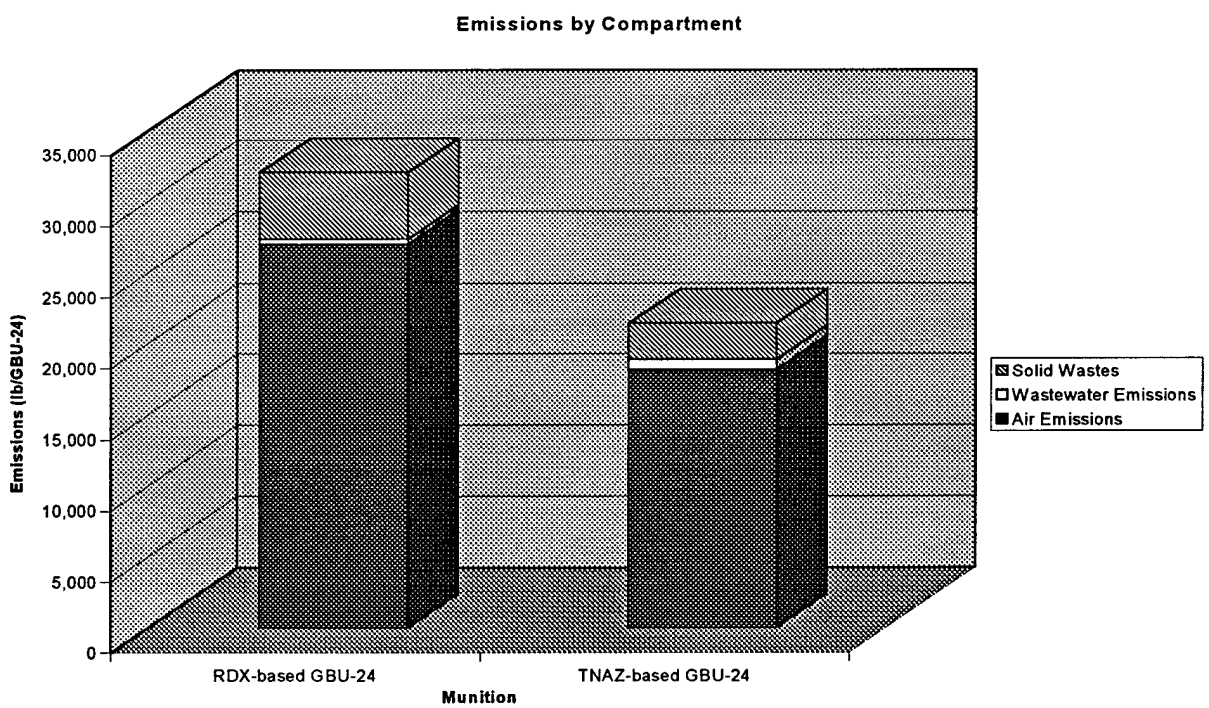


Figure 4-2. Emissions by compartment.

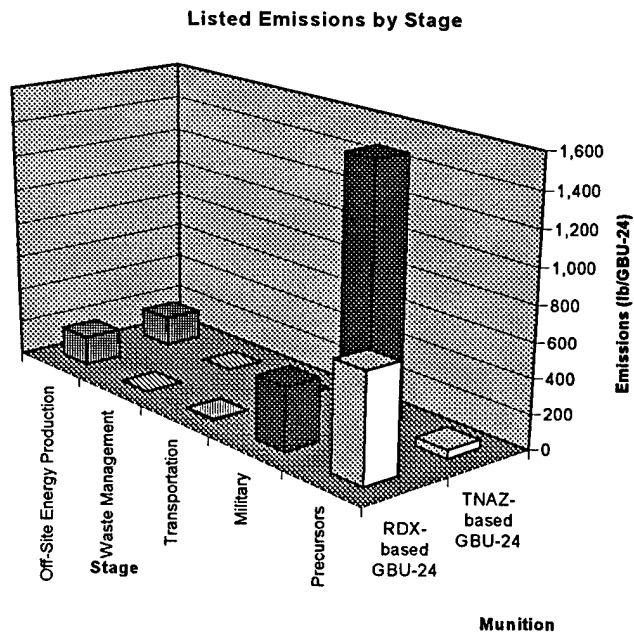


Figure 4-3. Listed emissions by stage.

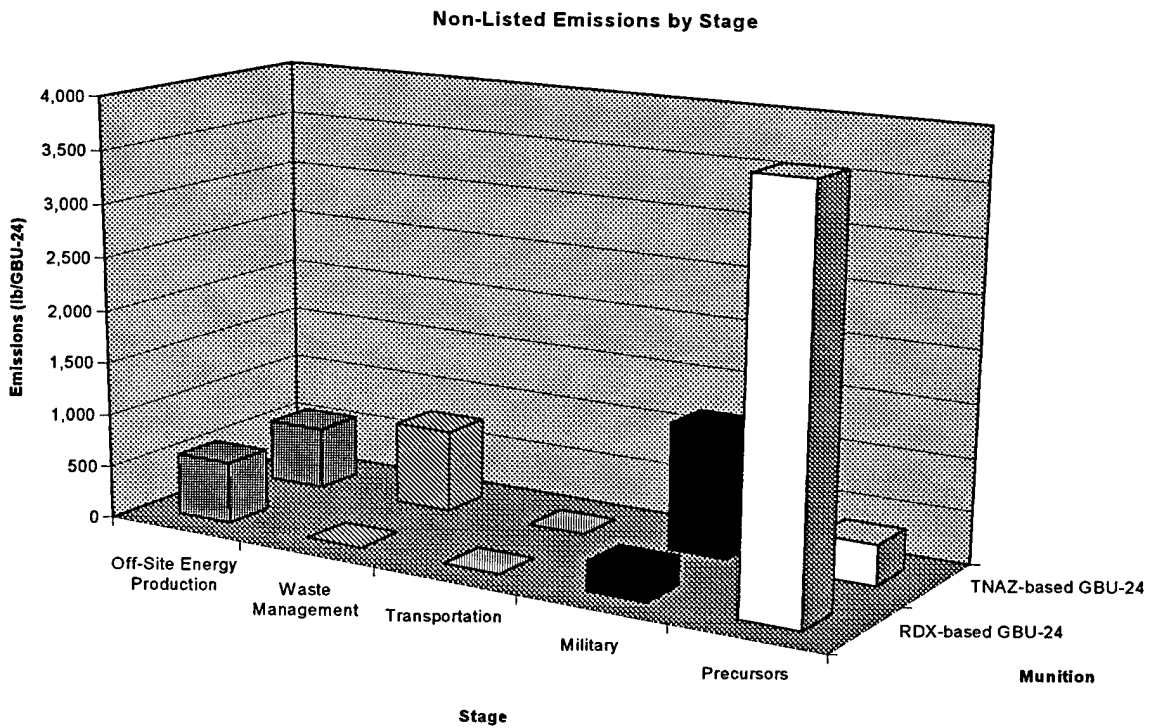


Figure 4-4. Non-Listed emissions by stage.

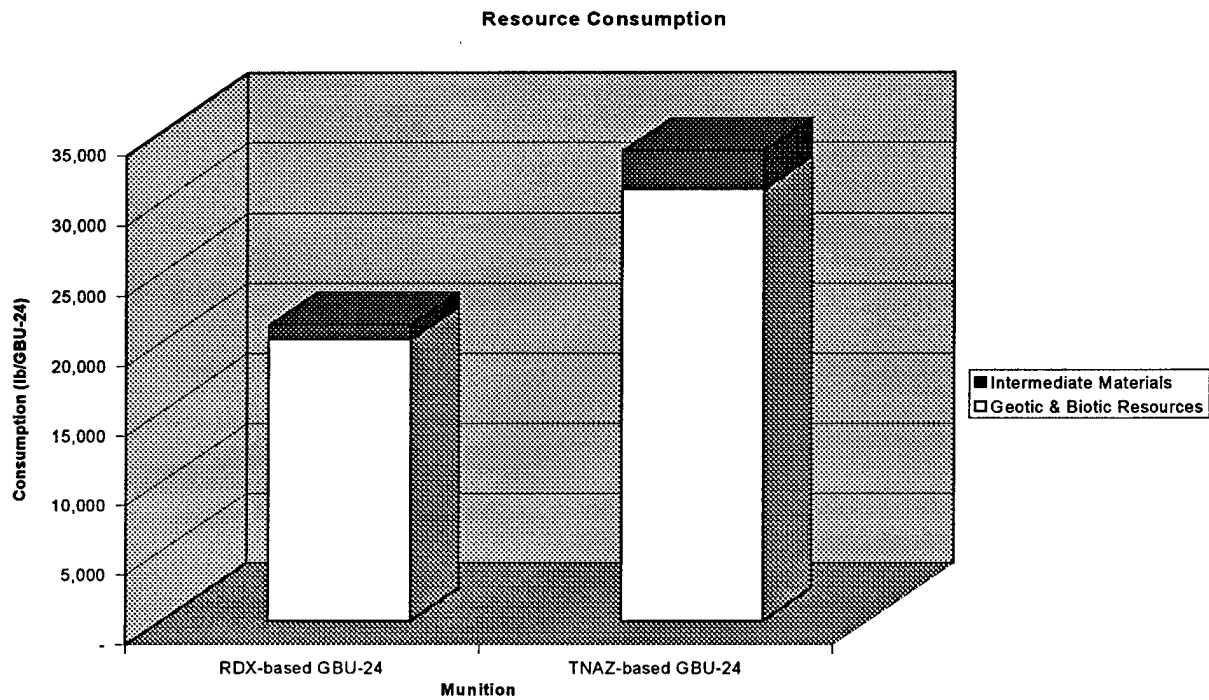


Figure 4-5. Resource consumption.

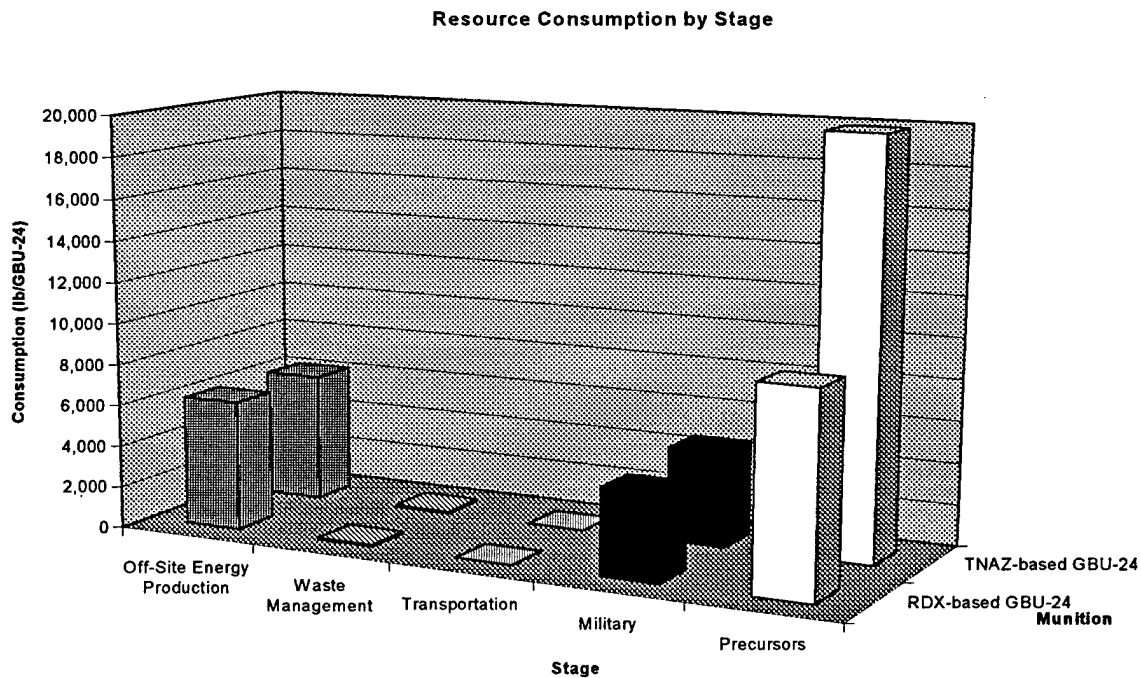


Figure 4-6. Resource consumption by stage.

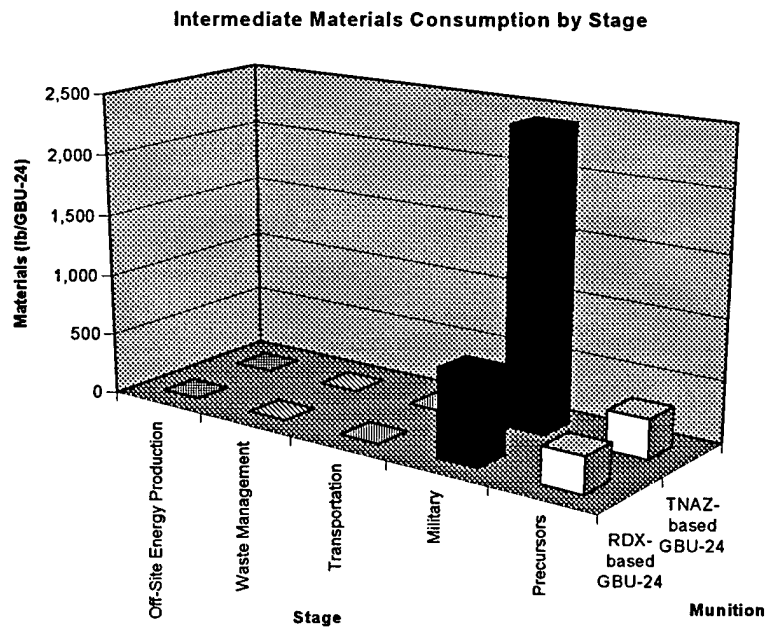


Figure 4-7. Intermediate materials consumption by stage.

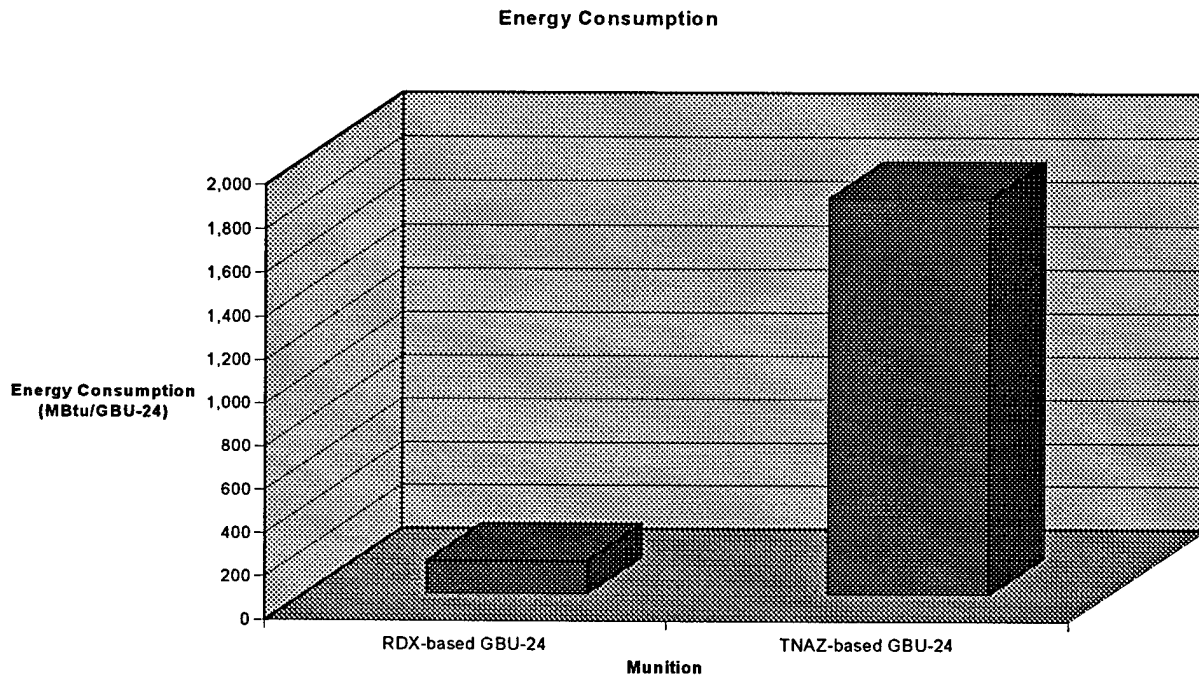


Figure 4-8. Energy consumption.

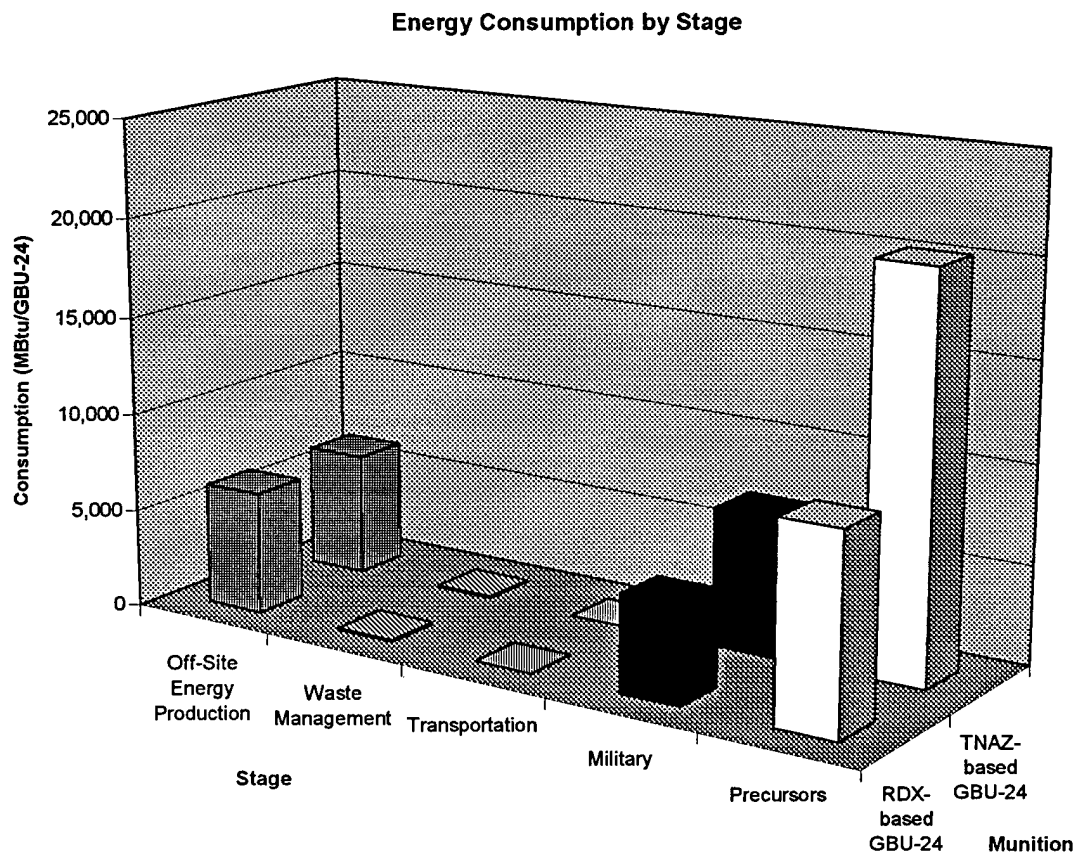


Figure 4-9. Energy consumption by stage.

5.0 Discussion

The RDX-based GBU-24 is better in 15 of the categories in Table 4-9, the TNAZ-based munition in one. For 19 of the categories there is no clear winner given the data available. By examining Tables 4-1 through 4-8 it can be seen that where the RDX-based munition is better it is generally much better, whereas the TNAZ-based GBU-24 is better by just more than the 15 percent differentiability margin.

Given the relative state of optimization for the systems, it is reasonable to expect the gap between the TNAZ-based and RDX-based systems to narrow for those comparators where the RDX-based system is better. The RDX-based system being a mature technology would not be expected to see significant changes in emissions or consumption. The same may not be said for the TNAZ-based system since much work on optimization of the synthesis reactions is occurring, which will be followed by further optimization achieved through large scale production. This action would be expected to tip the balance away from the RDX-based system being better in so many comparators.

Other unknowns include the true values for Transportation-, Waste Management-, and Off-site Electricity Production-related emissions for the TNAZ-based system. As was discussed above, no data were available on these activities from the LANL modeling efforts so a judgement was made to substitute the equivalent information from the RDX-based system.

These substitutions directly produce ties in 15 of the comparators. Some of these values are probably close to the true value, such as the Transportation-related emissions and consumption where the masses and distances traveled may not change much between the systems. Emissions from Waste Management may actually be lower than modeled for the TNAZ-based system since the TNAZ is recycled; however, Resource and Energy Consumption may increase since the TNAZ is melted out of the bomb casing. Off-site Electricity Production Emissions and Consumption are also expected to decrease since the amount of electricity used for the TNAZ-based system is approximately one-half that used for the RDX-based system. This would have the effect of changing seven of the comparators from a tie to being better under the TNAZ-based system (Total Non-Listed Emissions, Air Emissions, Listed Emissions - Off-site Electricity Production, Non-Listed Emissions - Off-site Electricity Production, Geologic and Biotic Resource Consumption - Off-site Electricity Production, Intermediate Materials Consumption - Off-site Electricity Production, and Energy Consumption - Off-site Electricity Production).

Based upon this qualitative analysis the true picture might look like Table 5-1. The RDX-based munition is better for 18 comparators, the TNAZ-based munition for 10, and which of the two systems is better cannot be determined for seven comparators.

Table 5-1. Life Cycle Inventory Summary Comparison (after Qualitative Adjustments for Data Quality)

Comparator	RDX-based GBU-24	TNAZ-based GBU-24
Total Emissions	.	.
Listed Emissions	.	.
Non-Listed Emissions	.	.
Air Emissions	.	.
Wastewater Emissions	.	.
Solid Wastes	.	.
Listed Emissions - Precursor Production	.	.
Listed Emissions - Military Facilities	.	.
Listed Emissions - Transportation	.	.
Listed Emissions - Waste Management	.	.
Listed Emissions - Off-site Electricity Production	.	.
Non-Listed Emissions - Precursor Production	.	.
Non-Listed Emissions - Military Facilities	.	.

Comparator	RDX-based GBU-24	TNAZ-based GBU-24
Non-Listed Emissions - Transportation		
Non-Listed Emissions - Waste Management		•
Non-Listed Emissions - Off-site Electricity Production		•
Total Resource Consumption	•	
Geologic and Biotic Resources	•	
Intermediate Materials	•	
Geologic and Biotic Resources - Precursor Production	•	
Geologic and Biotic Resources - Military Facilities		
Geologic and Biotic Resources - Transportation		
Geologic and Biotic Resources - Waste Management	•	
Geologic and Biotic Resources - Off-site Electricity Generation		•
Intermediate Materials - Precursor Production	•	
Intermediate Materials - Military Facilities	•	
Intermediate Materials - Transportation		
Intermediate Materials - Waste Management	•	
Intermediate Materials - Off-site Electricity Generation		•
Total Energy Consumption	•	
Energy Consumption - Precursor Production	•	
Energy Consumption - Military Facilities	•	
Energy Consumption - Transportation		
Energy Consumption - Waste Management	•	
Energy Consumption - Off-site Electricity Generation		•

Two points can be made. First, the RDX-based system appears to be the more environmentally beneficial at this time. Second, the TNAZ-based system does not appear to offer the potential to reduce the amount of Listed wastes emitted during GBU-24 production by the 50 percent goal. In fact, the TNAZ-based system will likely *increase* the amount of listed waste emitted. Currently the TNAZ-based system produces an estimated 18 pounds of Listed waste for every pound of Listed waste produced by the RDX-based system. To meet the goal, the TNAZ-based system would need to see a reduction in Listed wastes emitted of over 97 percent from current estimates.

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Appendix A

RDX-based GBU-24 LCI Inventory

Quantities by Site or Life Cycle Stage (in lb/GBU-24 unless noted otherwise)										
Item	RMA & Offsite Material Processing	HSAAP		MCAAP		NSWC-IH Demil.	Transport. (All)	Service/ Waste Manage. Offsite	Energy Production Offsite	Total
		Material Processing	Energy Production	Material Processing	Energy Production					
Listed Wastes										
Air Emissions										
Acetic acid	0	21								21
Acetone		4		0						4
Aluminum powder				0						0
Cyanox dust				0						0
Cyclohexanone		4								4
Hydrocarbons	236						1			237
Nitric acid		0								0
NOx	96	2	16		34	11	3		61	223
SOx	26		44		0				108	177
Stoddard solvent				3						3
Wastewater Emissions										
Acetic acid	0									0
Acetone				0						0
Ammonia	0									0
Hydroxide	0									0
Methanol										0
Phenol	0									0
Sulfuric acid	4									4
Trichloroethane				7		217				224
Solid Wastes										
Aluminum				0						0
Aluminum oxide	255									255
Pot Liner	3									3
RDX				0						0
Styrene resin				3						3
Non-Listed Wastes										
Air Emissions										
Asphaltic particulates				1						1
CO	32		6		5	1	1		7	52
CO2	2,490	0	6,041	0	1,407	209	188	773	15,020	26,128
n-Heptane				0						0
n-Propyl acetate		1								1
Total Particulates	13		1		0				62	75
Unspecified	1		0		16				0	18
Wastewater Emissions										
Iron	1									1
n-Heptane				0						0
Oil	0									0
Other Acid	0									0
Other Metals	0									0
Sulfide	0									0
Total Dissolved Solids	96					12				108
Total Suspended Solids	4					12				16
Solid Wastes										
Aluminum sludge		41								41
Ash	41									41
Binder				0						0
Biosolids		55								55
Bottom ash			148						108	256
Catalyst				0						0
CXM-7		2		0						2
FGD Solids									149	149
Fly ash			188	</						

RMA & Offsite Material Processing	HSAAP		MCAAP		NSWC-IH Demil	Transport. (All)	Service/ Waste Manage. Offsite	Energy Production Offsite	Total
	Material Processing	Energy Production	Material Processing	Energy Production					

Quantities by Unit of Line Cycle Gauge (in thousands of tonnes) noted below:										
Item	RMA & Offsite Material Processing	HSAAP		MCAAP		NSWC-IH Demil	Transport. (All)	Service/Waste Manage. Offsite	Energy Production Offsite	Total
		Material Processing	Energy Production	Material Processing	Energy Production					

Figure 1. Schematic diagram of the experimental setup. The subject is seated in a chair and views the screen through a mirror. The screen displays the target (a red dot) and the starting position (a black dot). The subject's hand is positioned at the starting position. The distance between the starting position and the target is 10 cm. The subject is instructed to move the hand from the starting position to the target. The movement is recorded by a video camera. The data are analyzed using a computer program.

Air Emissions									
Acetic acid	0	21							21
Acetone		4		0					4
Aluminum powder				0					0
Cyanox dust				0					0
Cyclohexanone		4							4
Hydrocarbons	236						1		237
Nitric acid		0							0
NOx	96	2	16		34	11	3		223
SOx	26		44		0			108	177
Stoddard solvent				3					3

Acetic acid	0								0
Acetone			0						0
Ammonia	0								0
Hydroxide	0								0
Methanol									0
Phenol	0								0
Sulfuric acid	4								4
Trichloroethane			7		217				224

Aluminum				0					0
Aluminum oxide	255								255
Pot Liner	3								3
RDX				0					0
Styrene resin				3					3

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

Air Emissions										
Asphaltic particulates				1						1
CO	32		6		5	1	1		7	52
CO2	2,490	0	6,041	0	1,407	209	188	773	15,020	26,128
n-Heptane				0						0
n-Propyl acetate		1								1
Total Particulates	13		1		0				62	75
Unspecified	1		0		16				0	18

Iron	1								1
n-Heptane			0						0
Oil	0								0
Other Acid	0								0
Other Metals	0								0
Sulfide	0								0
Total Dissolved Solids	96				12				108
Total Suspended Solids	4				12				16

Aluminum sludge		41						41
Ash	41							41
Binder			0					0
Biosolids		55						55
Bottom ash			148				108	256
Catalyst			0					0
CXM-7		2	0					2
FGD Solids							149	149
Fly ash			188				386	574
PBXN-109			0					0
Recycle			(213)				(166)	(379)
Red Mud	155							155
Slag							41	41
Thermosetting compound			2					2
Unspecified Solid Waste	3,499							3,499

[illegible]

Geologic and Biotic Resources							
Bauxite	390						390
Coal	827	2,208				6,225	9,260
Iron ore	2,243						2,243
Lime	5						5
Natural gas	2,548			1,882		58	4,489
Nitrogen	32						32
Oxygen	114						114
Petroleum	3,454			88		42	3,584
Rock salt	16						16

Intermediate Materials									
Acetic acid	0	108							108
Acetone		4	0	0	0				4
Ammonia	253								253
Binders		48							48
Cyclohexanone		4							4
DOA	43								43
Formaldehyde		181							181
Hexamine		137							137
Propyl acetate		4							4
Trichloroethane				224					224
Triphenyl phosphate		3							3
Energy Consumption (in MBTU/GBU-24)									
Coal	12.1		25.9					73.0	111
Electricity			1.7		2.3	0.5	1.5		6
Natural Gas					28.9		0.9		30
Petroleum					1.9		1.2	0.9	4

Appendix B

TNAZ-Based GBU-24 LCI Life Cycle Inventory

Suggest eliminating rows not in system

GBU-24 Baseline Life Cycle Inventory

Quantities by Site or Life Cycle Stage (in lb/GBU-24 unless noted otherwise)											(TNAZ & Solvent Recycle)
Item	RMA & Offsite Material Processing	HSAAP		MCAAP		NSWC-IH Demil.	Transport. (All)	Service/ Waste Manage. Offsite	Energy Production Offsite	Total	
		Material Processing	Energy Production	Material Processing	Energy Production						
Listed Wastes											
Air Emissions											
Acetaldehyde	0									0	
Acetic acid										0	
Acetimide	0									0	
Acetone				0						0	
Acetonitrile	0									0	
Acid	0									0	
Acrolein	0									0	
Acrylamide	0									0	
Acrylic acid	0									0	
Acrylonitrile	0									0	
Alachlor/Metolachlor	0									0	
Aldehydes	0									0	
Aluminum powder				0						0	
Ammonia	4									4	
Atrazine	0									0	
Benzene	0									0	
Chlorine	5									5	
Chlorobenzene	0									0	
Chlorpyrifos	0									0	
Cyanazine	0									0	
Cyanox dust				0						0	
Cyclohexanone										0	
Dichlorobenzene	0									0	
Fonofos	0									0	
Hydrazine	0									0	
Hydrocarbons	1,256									1256	
Hydrogen chloride	9									9	
Hydrogen cyanide	0									0	
Hydrogen sulfide	0									0	
Isopropanol	0									0	
Metals	0									0	
Methane	0									0	
Nitric acid	0									0	
NO	0					3		1		1	
N2O	1									1	
NOx	22				34			3	61	121	
Organic acids	0									0	
Phosgene	0									0	
Producer gas	280									280	
Propene	0									0	
Propylene	0									0	
Pyridine	0									0	
SOx	94				0				108	202	
Sulfuric acid	0									0	
Stoddard solvent				3						3	
Toluene		1,982								1982	
Terbufos	0									0	
Wastewater Emissions											
Acetic acid										0	
Acetone				0						0	
Alachlor/Metalachlor	0									0	
Ammonia	0									0	
Atrazine	0									0	
Chlorine	240									240	
Chlorpyrifos	0									0	
Cyanazine	0									0	
Fonofos	0									0	
Hydrazine	2									2	
Hydroxide										0	
Methanol										0	
Organics	0									0	
Phenol	0									0	
Phosgene	10									10	
Pyridine	2,297									2297	
Pyridine hydrochloride	3,356									3356	
Sulfuric acid										0	
Terbufos	0									0	
Trichloroethane				7						7	
Solid Wastes											
Acetic acid		2,743								2743	
Acetaldehyde	4									4	
Acetamide	0									0	
Acetonitrile	0	2,864								2864	

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Acrolein	1								1
Acrylamide	0								0
Acrylic acid	2								2
Acrylonitrile	56								56
Aluminum			0						0
Aluminum oxide									0
Ammonia	0								0
BDNA, polymeric		122							122
BHMNA.HCL		991							991
DIAD.H2		991							991
Hydrogen chloride	0								0
Miscellaneous		22							22
Organics		99							99
Polyamine		84							84
Pot Liner									0
Potassium ferricyanide		198							198
2-Propanol		353							353
Pyridine	0								0
RDX			0						0
Solvent		1,029							1029
Styrene resin			3						3
TNAZ		42							42
Triphenylphosphine		1,348							1348

Non-Listed Wastes

Air Emissions									
Asphaltic particulates			1						1
CO	219			5	0	1		7	232
CO2	5,038		0	1,407	114	188	773	15,020	22,541
Fluoride	0								0
n-Heptane			0						0
Oxygen		44							44
PM10	15								15
n-Propyl acetate									0
Total Particulates	290			0				62	353
Unspecified				16				0	17

Wastewater Emissions									
Ammonium nitrate		63							63
BOD	1								1
COD	1								1
Iron									0
n-Heptane			0						0
Nitrates	6								6
Oil	0								0
Other Acid	2								2
Other Metals	2								2
Phosphorus	0								0
Potassium	1								1
Sodium	16								16
Sodium chloride		219							219
Sodium formate		252							252
Sodium hydroxide		0							0
Sodium nitrite		672							672
Sodium sulfate	11	2,003							2,014
Sulfide									0
Total Dissolved Solids	2								2
Total Suspended Solids	13								13
Water	11,631,971	21,321			1,534				

Solid Wastes									
Aluminum sludge					48				48
Ash	16				61				77
Binder			0						0
Biosolids									0
Bottom ash							108		108
Catalyst			0						0
CXM-7 TNAZ Exp. Material			0						0
Ethanol		1,260							1,260
FGD Solids							149		149
Formic acid		203							203
Fly ash							386		386
Molybdenum trioxide	0								0
Paraformaldehyde		96							96
PBXN-109			0		127				128
Propylene	0								0
Recycle							(166)		(166)
Red Mud									0
Salts		84							84
Slag							41		41
Thermosetting compound			2						2
Unspecified Solid Waste	656				5				661

Resource Consumption

Geologic and Biotic Resources									
Bauxite	1								1
Clay	0								0
Coal	1,363,352							6,225	1,369,576
Iron ore	4								4
Lime	149								149
Natural gas	2,154,926			1,882			58		2,156,866
Nitrogen									0
Oxygen									0
Petroleum	342,162			88	6		42		342,298
Phosphate rock	49								49
Potassium chloride	14								14
Rock salt	6,335								6,335
Sand	0								0
Soil	3,769								3,769
Sulfur	19								19
Water	2,491,013	8			2,591				2,493,612
Intermediate Materials									
Acetic acid	3,164								3,164
Acetone			4	0					4
Activated carbon	1				5				5
Ammonia	1								1
Antifoam Agent		0							0
Benzene	1,399								1,399
Binders									0
Chlorine	2,464								2,464
CO	272								272
Cyclohexanone									0
DOA									0
Eth3PO4	9								9
Ethylene glycol	0								0
Formaldehyde									0
Free Base		643							643
Freon	0								0
Hexamine									0
Hydrazine	155								155
Hydrochloric acid		160							160
Hydrogen peroxide		165							165
Isopropanol	582								582
Nitromethane		282							282
Paraformaldehyde		630							630
Phosgene	957								957
Potassium ferricyanide		198							198
2-Propanol		353							353
Propoene	639								639
Propyl acetate									0
Pyridine	4,594								4,594
Sodium hydroxide	24								24
Sodium nitrite		928							928
Sodium persulfate		2,003							2,003
Sulfuric acid	8								8
Toluene		1,982							1,982
Trichloroethane			224						224
Triphenyl phosphate									0
Energy Consumption (in MBTU/GBU-24)									
Steam	33				1,695				1,728
Coal				2.3				73.0	75
Electricity	1.2						1.5		3
Hydropotential	12.5								12
Natural Gas				28.9			0.9		30
Nuclear Energy	102.1								102
Petroleum				1.9		1.2	0.9		4

Appendix C

TNAZ-Based GBU-24 Life Cycle Inventory Model

TNAZ Precursors

lb/lb TNAZ	Precursor materials and inputs for TNAZ (Oct 95)	Factored Use lb/lb precursor	Module in LCI
1.33	Formaldehyde (37%)	1	
	1 Methanol	1	
	1 Synthesis gas	1	
	1.04631263 Coal	1.04631263	
	0.596333404 Oxygen	0.596333404	
	1.397873673 water	1.397873673	
	0.5 Air (Oxygen)	0.5	
3.29	NIB-Glycerol (50%)	1	
	0.331156299 Nitromethane	0.331156299	
	1 Petroleum gas	0.331156299	
	1 Nitric acid	0.331156299	
	0.3 Paraformaldehyde	0.3	
	0.662171432 Formaldehyde (37%)	0.19865143	
2.33	di isopropylazodicarboxylate	1	
	0.667651524 Azodicarboxyl Chloride	0.667651524	
	1.80902464 Phosgene	1.207798059	
	0.724068226 Chlorine	0.874528197	
	0.286032785 Carbon monoxide	0.345469842	
	0.0005 Activated Carbon	0.000603899	
	0.293090214 Hydrazine	0.353993792	
	1.37755102 Ammonia	0.487644509	
	3.403061224 Sodium Hypochlorite	1.204662547	
	0.238803573 NaOH	0.287677721	
	1.058327572 Chlorine	1.274927588	
	0.648379344 Chlorine	0.432891458	
	0.660415095 isopropanol	0.660415095	
	0.725707656 Propylene	0.479268291	
	0.008567382 Sulfuric acid	0.005658028	
3.02	Triphenyl phosphine	1	
	1.739385713 Grignard reagent of benzene	1.739385713	
	0.913761009 Chlorobenzene	1.589382845	
	0.685027408 Benzene	1.08877081	
	0.629945184 Chlorine	1.001224069	
	0.197350102 Magnesium	0.343267948	
	0.581718484 trichlorophosphine	0.581718484	
	0.237401689 Phosphorous	0.138100951	
	0.815298879 Chlorine	0.474274428	
5.57	Acetic anhydride	1	
	1.457117595 Acetic acid	1.457117595	
	0.485686352 Methanol	0.707702129	
	1.04631263 Coal	0.740477675	
	Carbon monoxide	0	
	0.428266893 Coal	0	
0.81	tert-butylamine	1	
	1.332284697 tert-butylchloride	1.332284697	
	0.673474147 2 methyl propylene	0.8972593	
	0.815171249 Chlorine	1.086040181	
	0.245109723 Ammonia	0.245109723	
	0.664519692 Sodium hydroxide	0.664519692	
8.8	Sodium hydroxide (50%)	1	
	0.59 rock salt	0.59	
1.11	Hydrochloric acid (37%)	1	
1.6	Hydrogen peroxide (50%)	1	
	0.056165471 Hydrogen	0.056165471	
	0.891481976 Oxygen	0.891481976	
	3 water	3	
	0.001 Ethyl anthroquinone Catalyst	0.001	
3.6	Iso propanol	1	
	0.9 Propylene	0.9	
	Crude oil	0	
	0.0125 Sulfuric acid	0.0125	
2.62	2 butanone (MEK)	1	
	1 2 butanol	1	
	1 n butene (mix)	1	
	1.879988255 Naphtha	1.879988255	
	1.73292E-05 ammonia	1.73292E-05	
2.27	Sodium nitrite (s)	1	

TNAZ Precursors

0.47 Potassium ferrocyanide	1
0.474903847 KCN	0.474903847
0.379525372 HCN	0.180238059
1.046829519 KCl (or KBr)	0.497143365
0.196704311 FeCN2	0.196704311
0.278354486 HCN	0.132191616
0.575163641 Fe (powder)	0.273147426
Iron ore	0
4.76 Sodium persulfate	1
1.213756073 Na2SO4	1.213756073
5 Methyl t-butyl ether (MTBE)	1
0.454373948 Methanol	0.454373948
0.8 methane	0.363499158
0.795628321 Isobutene	0.795628321
0.01 Iron chloride 42o Be	1
Iron metallic	0
Hydrochloric acid	0
0.92 Nitric acid (70%)	1
0.549672131 Ammonia	0.549672131
10.70491803 Air	10.70491803
0.56 ammonium nitrate (s)	1
0.21243083 Ammonia	0.21243083
0.909292035 Nitric acid	0.909292035
2.24 Ethanol SDA3A	1
Corn, sorghum	0
6.8 Acetonitrile	1
0.386722942 Ammonia	0.386722942
0.956630435 Propylene	0.956630435
10 Nitrogen gas	1
Air	0
100 Deionized water	1
Sulfuric acid	0
Sodium Hydroxide	0
Water (natural sweet)	0
0.01 Antifoam, DOW 2210	1

Formaldehyde LCI

Formaldehyde Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
NOx	0.000025
CO	0.041807
SOx	0.016888
Formaldehyde	0.000005
Methanol	1.21E-05
Ammonia	1.46E-07
Sulfuric acid	2.22E-09
TSP	0.007691
CO2	0.102758
Hydrocarbons	0.031006

Water

Solid Wastes

Production waste (not inert)	0.032566

Resource Consumption

Energy	2.812753 kWh/lb
Oxygen (from air)	0.53
Natural Gas	0.202
CO2	0.183
Water	0.127
Methanol	0.47
Air	5.76
Coal	0.428267

NIB-Glycerol Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air Emissions	
1,2-butylene oxide	1.9869E-07
2-nitropropane	0.00017369
acetaldehyde	2.0085E-05
acetone	1.3478E-05
acetonitrile	6.9212E-06
ammonia	0.00025343
BrClF2C	6.292E-07
BrF3C	2.3678E-06
Chlorine	1.2915E-06
Cl2F2C	0.0003146
Formaldehyde	0.00010352
Hydrogen cyanide	1.8396E-05
methanol	7.8202E-06
naphthalene	0.00018358
nitric acid	1.573E-06
NOx	8.3961E-06
CO	0.00830507
SOx	0.00335492
Sulfuric acid	4.4145E-10
TSP	0.00152788
CO2	0.02041303
Hydrocarbons	0.00615947
Wastewater Emissions	
ammonia	4.9673E-07
Hydrogen cyanide	3.3116E-08
2-nitropropane	
acetaldehyde	0.00297512
acetone	0.00159669
acetonitrile	0.00130257
ammonia	4.0683E-05
Formaldehyde	2.2717E-05
Hydrogen cyanide	1.8876E-06
methanol	0.00262238
naphthalene	1.8876E-06
nitric acid	0.00018373
Wastewater	23.0110595
Solid Wastes	
Production waste (not inert)	0.00646925

Resource Consumption

Steam	0.00976429	
River Water	23.0012953	
Electricity	0.01192499	kWh
Energy	0.55875742	kWh
Oxygen (from air)	0.10528526	
Natural Gas	0.04012759	
CO2	0.03635321	
Water	0.02522873	
Air	1.14423223	
Coal	0.08507583	

Diisopropylazodicarboxylate Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
Phosgene	5.78E-05
Hydrazine	3.56E-07
Isopropanol	6.2E-07
Pyridine	5.59E-06
HCl	1.59E-05
Cl ₂	1.71E-05
CO	0.004051
TSP (PM-10)	0.000383
SO _x	0.002005
NO _x	0.002876
CO ₂	0.849661
Ammonia	0.001024
Methane	3.64E-10
Hydrocarbons	0.006136
Isopropanol	0.000431
Propene	1.69E-05
H ₂ S	4.79E-06
Heavy metals	4.79E-07
H ₂ SO ₄	3.62E-07
Wastewater	
Phosgene	0.009784
Hydrazine	0.001585
Pyridine	2.34707
Pyridine HCl	3.428944
Na ₂ SO ₄	0.011167
COD	0.000113
BOD	2.3E-05
Acid as H ⁺	0.000995
Metal ions	0.000354
Cl ₂	0.120565
Dissolved Organics	9.59E-06
Total Suspended Solids	0.005836
Crude oil	4.79E-05
Total Dissolved Solids	0.000335
Phenol	3.35E-05
Sodium	0.008036
Solid Wastes	
Production waste (not inert)	0.288446

Resource Consumption

Phosgene	0.978355
Hydrazine	0.158474
Isopropanol	0.594389
Cl2	1.220271
Pyridine	4.694139
CO	0.277794
Activated Carbon	0.000604
Natural Gas	1.03912
Electric Power	0.067589 kWh
Steam	0.185305
Heat Energy (fossil fuel)	0.433116 kWh
Propene	0.653158
Sulfuric acid	0.007711
NaOH	0.006289
Coal	0.698641
Hydropower	2.128203
Fission	17.67491
Iron ore	0.001774
Limestone	0.0511
Bauxite	0.000144
Rock salt	3.297246
Clay	9.59E-06
Water	4.615634
Crude Oil	0.242245
Sand	5.74E-05

Triphenyl phosphine LCI

Triphenyl phosphine Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
Cl ₂	0.003882
Benzene	4.92E-06
HCl	0.006726
dichlorobenzenes	3.98E-06
chlorobenzene	6.48E-05

Water	
COD	0.000233
BOD	2.62E-05
Acid as H ⁺	0.000545
Metal ions	0.000525
Cl ₂	0.062069
Total Suspended Solids	0.003082
Crude oil	0.000109
Total Dissolved Solids	0.000662
Hydrocarbons	0.000103
Phenol	1.09E-06
Sodium	0.004131

Solid Wastes	
Production waste (not inert)	0.156592

Resource Consumption	
Heat Energy (fossil fuel)	0.880406 kWh
Electric Power	4.73E-06 kWh
Benzene	1.102986
Chlorine	1.00113
Sodium hydroxide (dry basis)	0.013772
Natural Gas	1.159743
Crude Oil	0.83093
Coal	0.383234
Hydropower	1.138573
Fission	9.277315
Iron ore	0.001122
Limestone	0.027564
Bauxite	0.00024
Rock salt	1.791668
Clay	2.18E-05
Water	3.733043
Sand	2.95E-05

Acetic anhydride Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
Producer gas	0.129049
Cinder	0.110446
Flue gas	0.494985
TSP	0.01665
SOx	0.03655
CO	0.090473
CO2	0.222453
Hydrocarbons	0.067123
Wastewater	
Water	5347.48
Solid Waste	
Production waste (not inert)	0.023047
Resource Consumption	
AcOH	1.457118
NH3	0.000284
Eth3PO4	0.004325
Air	0.251604
Natural Gas	0.015179
EthGlycol	2.68E-05
Freon	2.72E-06
Filtered Water	6.638878
Steam	7.593786
River Water	803.3346
Coal	0.927121

tert-Butylamine Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
TSP (PM-10)	1.45E-10
SOx	7.06E-06
NOx	1.5E-09
CO	0.001936
CO2	0.299867
Ammonia	0.000515
Methane	1.83E-10
Hydrocarbons	0.001157
Water	
COD	1.75E-05
BOD	5.25E-06
Acid as H+	0.000595
Metal ions	0.000158
Cl2	0.073524
Total Suspended Solids	0.003501
Total Dissolved Solids	8.75E-05
Sodium	0.004902
Solid Wastes	
Production waste (not innert)	0.173305
Resource Consumption	
Natural Gas	0.471558
Crude Oil	0.172421
Coal	0.407813
Hydropower	0.160052 kWh
Fission	1.337611 kWh
Iron ore	0.001012
Limestone	0.027178
Rock salt	1.706175
Water	4.499391
Sand	3.5E-05
Electric Power	0.033972 kWh
Steam	0.011736 kWh

Sodium hydroxide LCI

Sodium hydroxide Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
Water	
COD	0.00001
BOD	0.000003
Acid as H+	0.00034
Metal ions	0.00009
Cl2	0.042
Total Suspended Solids	0.002
Total Dissolved solids	0.00005
Sodium	0.0028
Solid Wastes	
Production waste (not inert)	0.099
Resource Consumption	
Natural Gas	0.176505
Crude Oil	0.129783
Coal	0.217294
Hydropower	0.09259 kWh
Fission	0.748543 kWh
Iron ore	0.00046
Limestone	0.0105
Rock salt	0.59
Water	5.3
Sand	0.00002

Isopropanol LCI

Isopropanol Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
Isopropanol	0.000652
Propene	2.56E-05
TSP	0.00072
SOx	0.003763
NOx	0.0054
CO	0.00036
CO2	0.475251
H2S	0.000009
HCl	0.000009
Hydrocarbons	0.007201
Heavy metals	9E-07
H2SO4	8E-07

Water	
Na2SO4	0.01691
COD	0.00018
BOD	0.000027
Acid as H+	0.000036
Metal ions	0.00018
Cl2	0.000045
Dissolved Organics	0.000018
Total Suspended Solids	0.00018
Crude oil	0.00009
Total Dissolved Solids	0.00036
Phenol	0.000063

Solid Wastes

Production waste (not inert)	0.0081

Resource Consumption

Heat Energy (fossil fuel)	0.655825
Electric Power	4.68E-06
Propene	0.989011
Natural Gas	0.462717 kWh
Coal	0.018379 kWh
Hydropower	0.013608
Fission	0.026082
Iron ore	0.00018
Limestone	0.00009 kWh
Bauxite	0.00027 kWh

Isopropanol LCI

Rock salt	0.0054
Clay	0.000018
Water	1.44

MEK Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
Cl ₂	4.18E-06
Zinc oxides/Phosphates	1.136721
TSP	0.0008
SO _x	0.004
NO _x	0.006
CO	0.0004
CO ₂	0.500021
H ₂ S	0.000001
HCl	0.00001
Hydrocarbons	0.007001
Heavy metals	0.000001
Ammonia	3.64E-08
Methane	1.29E-14
Water	
Dissolved Organics	3.73E-05
COD	0.0002
BOD	0.00004
Acid as H ⁺	0.00004
Metal ions	0.0003
Cl ₂	0.00005
Total Suspended Solids	0.0002
Crude oil	0.0001
Total dissolved Solids	0.0004
Hydrocarbons	0.00009
Phenol	0.000001
Solid Wastes	
P4 production waste (not inert)	5.85E-07
Zinc Compounds	3.8E-05
Production waste (not inert)	0.0083
Resource Consumption	
Chlorine	1.73E-05
Natural Gas	0.67741
Crude Oil	0.825106
Coal	0.017555
Hydropower	0.00756 kWh
Fission	0.02772 kWh
Iron ore	0.0002

MEK LCI

Limestone	0.0001
Bauxite	0.0003
Rock salt	0.006
Clay	0.00002
Water	1.6
Electric Power	2.4E-06 kWh
Steam	8.3E-07 kWh

MTBE Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
MTBE	7.32E-06
Methanol	2.14E-05
Ammonia	4.09E-09
TSP	0.004131
SOx	0.010854
CO	0.019308
CO2	0.444505
Hydrocarbons	0.019659
NOx	0.004774
H2S	7.96E-07
HCl	7.96E-06
Heavy metals	7.96E-07

Water	
MTBE	3.26E-08
Methanol	5.43E-06
Ammonia	1.66E-07
COD	0.000159
BOD	3.18E-05
Acid as H+	3.18E-05
Metal ions	0.000239
Cl2	3.98E-05
Dissolved Organics	1.59E-05
Total Suspended Solids	0.000159
Crude oil	7.96E-05
Total Dissolved Solids	0.000318
Hydrocarbons	7.16E-05
Phenol	7.96E-07

Solid Wastes	
Production waste (not inert)	0.021401

Resource Consumption	
Electric Power	1.25E-08 kWh
Isobutylene	0.844446
Methanol	0.273011
Coal	0.208561
Natural Gas	0.538952
Crude Oil	0.656478
Hydropower	0.006015 kWh

MTBE LCI

Fission	0.022054 kWh
Iron ore	0.000159
Limestone	7.96E-05
Bauxite	0.000239
Rock salt	0.004774
Clay	1.59E-05
Water	1.273005

Nitric acid LCI

Nitric acid Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
NOx	1.04E-05
TSP (PM-10)	3.25E-10
SOx	1.58E-05
CO	0.004342
CO2	0.672469
Ammonia	0.001154
Methane	4.11E-10
other organic	0.002594

Wastewater

Water	69.48701

Solid Waste

Resource Consumption

Steam	0.029485
River Water	69.45752
Electricity	0.112193 kWh
Natural Gas	0.580032
Steam	0.026318 kWh

Ammonium nitrate LCI

Ammonium nitrate Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
NOx	1.37E-05
Wastewater	
Water	91.78143
Solid Waste	
Resource Consumption	
Steam	0.038946 kWh
River Water	91.74249
Electricity	0.047564 kWh

Ethanol Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
NOx	0.002435
SOx	0.001701
PM-10	0.011892
Total Particulate	0.009237
CO	0.00573
CO2	0.547669
Non-Methane Org. Comp.	0.000729
Methane	3.09E-06
N2O	0.000272
HCL	7.26E-06
Ammonia	0.000443
Chlorine	7.95E-07
Sulfuric Acid	4.9E-07
Hydrocarbons	0.000343
Aldehydes	1.67E-05
Organic Acids	1.32E-06
Fertilizer N2O	0.000411
Fertilizer NO	0.000252
Particulate	0.000139
Nitric Acid	6.13E-06
Fluoride	5.58E-07
Acid Mist	3.14E-05
Herbicides	0.000157
Alachlor	3.13E-05
Atrazine	5.78E-05
Metalachlor	3.83E-05
Cyanazine	2.99E-05
Insecticides	2.49E-05
Fonofos	4.64E-06
Turbufos	1.23E-05
Chlorpyrifos	7.98E-06
Water	
Total Water Emission	0.610304
Ammonia	5.7E-06
Chlorine	3.26E-08
BOD5	0.000407
TSS	0.000509
Herbicides	6.11E-06
Alachlor	2.74E-07

Ethanol LCI

Atrazine	2.97E-06
Metalachlor	1.2E-06
Cyanazine	1.67E-06
Insecticides	5.2E-07
Fonofos	8E-08
Turbufos	2.12E-07
Chlorpyrifos	2.28E-07
Nitrates (as nitrogen)	0.004885
Phosphorous	0.000122
Potassium	0.000504

Solid Wastes

HCL	1.12E-07
Ammonia	1.83E-07
Coal Ash	0.012993

Resource Consumption

Natural gas	1705.936	
Coal	1079.272	
Electricity	0.084213	kWh
Water	276.1801	
Sulfur	0.001175	
Diesel	444.8868	Btu
LPG	99.77364	
Oil	58.12006	
Gasoline	112.5477	
Limestone	0.039864	
Sulfur	0.013546	
Water	275.4681	
Phosphate Rock	0.038957	
Potassium Chloride	0.011404	
Soil	2.991136	

Acetonitrile Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
Cl ₂	1.33E-06
Acetonitrile	6.25E-06
Acrolein	1.22E-07
Acrylic acid	4.16E-09
Acrylonitrile	4.5E-05
Ammonia	0.000824
Hydrogen Cyanide	6.69E-05
Propylene	2.3E-05
Acetamide	1.39E-08
Acetaldehyde	5.41E-08
Acrylamide	3.09E-07
Pyridine	2.11E-07
Hydrocarbons	0.009633
TSP (PM-10)	0.000765
SO _x	0.003838
NO _x	0.00574
CO	0.003438
CO ₂	0.978218
Methane	2.89E-10
H ₂ S	9.57E-06
HCl	9.57E-06
Heavy metals	9.57E-07
Water	
Ammonia	4.02E-07
COD	0.000191
BOD	2.87E-05
Acid as H ⁺	3.83E-05
Metal ions	0.000191
Cl ₂	4.78E-05
Dissolved Organics	1.91E-05
Total Suspended Solids	0.000191
Crude oil	9.57E-05
Total Dissolved Solids	0.000383
Phenol	6.7E-05
Solid Wastes	
Acetonitrile	6.8E-08
Acrylonitrile	6.94E-09
Acetonitrile	4.72E-07

Acetonitrile LCI

Acrolein	0.000222
Acrylic acid	0.000861
Acrylonitrile	0.019429
Ammonia	2.91E-05
Molybdenum Trioxide	2.64E-05
Acetamide	8.32E-06
Acetaldehyde	0.001291
Acrylamide	0.000112
Pyridine	1.53E-08
LCI component	0.005274
Propylene	7.63E-05
Molybdenum Trioxide	0.000124
Production waste (not inert)	0.00861

Resource Consumption

Heat Energy (fossil fuel)	0.112889	kWh
Electric Power	0.053599	kWh
Natural Gas	0.899915	
Steam	0.018516	kWh
Coal	0.019536	
Hydropower	0.014464	kWh
Fission	0.027723	kWh
Iron ore	0.000191	
Limestone	9.57E-05	
Bauxite	0.000287	
Rock salt	0.00574	
Clay	1.91E-05	
Water	1.530609	

Mass Balance on Unit Processes
Brown, Hamel and Hedman

Process No. (- = inflow, + = outflow)						
Material	1	2	3	4	5	6 Total
Methanol	-0.54				0.07	-0.47
Air	-1.55		-0.81			-3.4
Steam	-0.05	-0.5				0.55
Mixture	2.14	0	0	-1.07	-1.07	0
Loss						0
Condensate		0.5				0
Fuel						-0.5
Stack gas			0.81			3.4
Cooling water				0		4.21
Off gas				1.07		0
Formaldehyde					1	1.07
Makeup						1
Total	4.44089E-16	0	0	0	0	-0.05
					2.64E-16	7.08E-16

Notes: Inputs and outputs are lb. per lb. of formaldehyde produced.

Energy Balance on Unit Processes
Brown, Hamel and Hedman

Process No. (- = inflow, + = outflow)						
Material	1	2	3	4	5	6 Total
Methanol	-4				4	0
Air						0
Steam	-60	-620				0
Mixture	58	342	500	-840	-60	680
						0

	6	226.5	120	90	4	30.7	477.2
Loss							
Condensate		51.5				-51.5	0
Fuel			-800			-967	-1767
Stack gas			180			307.8	487.8
Cooling water				690			690
Off gas				60			60
Formaldehyde					52		52
Makeup							0
Total	0	0	0	0	0	5.68E-14	5.68E-14

Notes: Inputs and outputs are in BTU per lb. of formaldehyde produced.

Sheet Title: Methanol (for Acetic acid production by Eastman/Malinkrodt at Kingston)

Sheet Description: Engineering calculation (rough)
This page calculates the vendor emissions from a plant producing Acetic acid.
Not included are raw material production or extraction or water and energy use.
(Energy balance is assumed to be close to 0 due to exothermic producer gas synthesis process)

References/Citations: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

Kirk Othmer Encyclopaedia of Chemical Technology
2nd ED, 1964 and 4th Ed, 1991-4
Wiley Interscience,

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units
Acetic acid	1.00E+00	kg
Coal Tar	1.05E-01	Kg
Total	1.10515212	Kg

Notes: Bbl eq. are calculated on a energy content basis and used to calculate the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
TSP	Kg/Kg Acetic a	0.0085		Kg/Kg Acetic a	0.007691249		3
SOx	Kg/Kg Acetic a	0.018658783		Kg/Kg Acetic a	0.016883452		3
CO	Kg/Kg Acetic a	0.046186813		Kg/Kg Acetic a	0.041792268		3
CO2	Kg/Kg Acetic a	0.113563242		Kg/Kg Acetic a	0.102758018		3
total HC's	Kg/Kg Acetic a	0.034266829		Kg/Kg Acetic a	0.031006436		3
Water							
Solid Wastes							
Production waste	Kg/Kg Acetic a	0.035990206			0.032565839		
Resource Consumption							
Coal	Kg/Kg Acetic a	0.473300065		Kg/Kg Acetic a	0.428266893		
Methanol	Kg/Kg Acetic a	0.536757301		Kg/Kg Acetic a	0.485686352		

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference
BTU	J	1055.056	CRC, 66th Edition
Wh	J	3600	CRC, 66th Edition
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%
gal	L	3.785412	CRC, 66th Edition
kg	lb	2.2046226	CRC, 66th Edition
yr	day	365	
m ³	bbl (petroleum)	6.289811	CRC, 66th Edition
gal CrO	lb CrO	7.2	
ton	lb	2000	
gal fuel oil	BTU fuel oil	138000	
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.
lb Coal (dry)	BTU Coal	12000	calculation page B SD=11%
kg NG	MJ NG	46	Calculated page C SD=13%

Calculations

Acetic acid Production

Energy input

All energy is assumed to come from the heat of combustion in the formation of CO, which is recoverable.

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Coal	MJ/kg ethylene	0			3 kg/kg ethylene	0	
Oil	MJ/kg ethylene	0	15		3 kg/kg ethylene	0	0.33622909
Natural Gas	MJ/kg ethylene	0			3 kg/kg ethylene	0	
Hydropower	MJ/kg ethylene	0			3		
Fission	MJ/kg ethylene	0			3		

Probably different mix in US

Material input

Source: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Methanol Carbonylation method

Stoichiometric ratios:

Methanol net	Kg/Kg Acetic a	0.533		
CO net	Kg/Kg Acetic a	0.467		
Methanol input	Kg/Kg Acetic a	0.536757301	0.993	0.993 conversion of methanol
CO input	Kg/Kg Acetic a	0.513186813	0.91	0.91 conversion of CO
Producer-Gas input	Kg/Kg Acetic a	1.694973756		from Faith Keyes and Clark's Industrial chemicals, 1975
Coal input	Kg/Kg Acetic a	0.473300065		

Emission calculation (Data from pg D and from AP42 Ed 4 Tbl 1.1-1)

Air				
CO released from process	Kg/Kg Acetic a	0.046186813	0.09	unconverted CO
Methane	Kg/Kg Acetic a	0.030509528		
CO2	Kg/Kg Acetic a	0.113563242		
Particulates	Kg/Kg Acetic a	0.0085	8.5	g/kg in Cyclone trap outlet (AP42 Ed 4 tbl 1.1-1)
Methanol	Kg/Kg Acetic a	0.003757301	0.007	unconverted assumed to escape in vent stream
SOx	Kg/Kg Acetic a	0.018658783	19.5**S in Co from AP 42 Ed 4 (1985) tbl 1.1-1	Coal assumed to have 1% Sulfur and the coal tar product to have 0.4% sulfur

Land

Ash	Kg/Kg Acetic a	0.035990206	0.094	Ash in coal (assumed recovered) but for air emission

CO production from Coal through synthesis gas (producer or manufactured)

Source: Page D calculations

Producer gas from Coal (Baddelsey)

25.30% mol CO 30.28% wt CO

Mw CO 28.016

Mw Produc 23.410686

Gas product yield from coal: 3.581182178 lb gas/lb coal

Co-Products:

source: calculated from data on this sheet and on sheet D

Coal tar heating value is median for data of Perry Ed 6 (1984) tbl. 9-12

Coal Tar	Kg/Kg Acetic a	0.10515212		
Energy equivalent	MJ/Kg Acetic a	4.153508743	39.5	MJ/Kg coal tar

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil					Kg/Kg Acetic acid		
Natural Gas					Kg/Kg Acetic acid		
Coal	Kg/Kg Acetic a	0.473300065			3 Kg/Kg Acetic acid	0.473300065	
Iron ore	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Methanol	Kg/Kg Acetic a	0.536757301			3 Kg/Kg Acetic acid	0.536757301	
Bauxite	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Rock salt	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Clay	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

Output

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/Kg Acetic a	0.0085			Kg/Kg Acetic acid	0.0085	
SOx	Kg/Kg Acetic a	0.018658783			Kg/Kg Acetic acid	0.018658783	
NOx	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
CO	Kg/Kg Acetic a	0.046186813			Kg/Kg Acetic acid	0.046186813	
CO2	Kg/Kg Acetic a	0.113563242			Kg/Kg Acetic acid	0.113563242	
H2S	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
HCl	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
total HC's	Kg/Kg Acetic a	0.034266829			Kg/Kg Acetic acid	0.034266829	
other organic	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Heavy metals	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
BOD	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Acid as H+	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Metal ions	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Cl2	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Dissolved Organics	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
suspended solids	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
crude oil	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
miscellaneous dissolved mate	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Phenol	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not inert)	Kg/Kg Acetic a	0.035990206			Kg/Kg Acetic acid	0.00128	
Toxic chemicals	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0.000001	

Coal type	Moisture	Sulfur	%dry	Heat value				
	%	%		Btu/lb	Btu/lbdry			
Sub bit C	26	0.3	0.41	8230	11121.62			
HV bit A	2.9	0.6	0.62	14170	14593.2	low sulfur coal heating value		
Sub bit B	22.2	0.5	0.64	9610	12352.19			
Brown Coa German - R	55	0.3	0.67	4830	10733.33			
Sub bit A	13.9	0.6	0.70	10330	11997.68	SD=	1295.775	0.108169
Meta Anthracite	9	0.7	0.77	10080	11076.92	Avg=	11979.16	
LV bit	2.9	0.8	0.82	14400	14830.07	median		
Anthracite	4.3	0.8	0.84	12880	13458.73		27.86352	MJ/kg
Lignite	36.8	0.9	1.42	7000	11075.95		dry base	
MV bit	2.4	1.5	1.54	14490	14846.31			
Semi anthracite	2.1	1.7	1.74	13700	13993.87			
HV bit B	6.7	2.6	2.79	12390	13279.74			
HV bit C	15.4	2.9	3.43	10740	12695.04			

bit=Bituminous

V=Volatility

L=low

M=Medium

H=high

Source: Kirk Othmer vol 4 1949

Mwt heat value Rio Arriba, Terrell, TexStanton, KaSan Juan, NOlds Field, Cliffside, Texas

mol% MJ/M^3

Methane	16.043	37.57	96.91	45.64	67.56	77.28	52.34	65.8			
ethane	30.07	65.83	1.33	0.21	6.23	11.18	0.41	3.8			
propane	44.097	93.6	0.19		3.18	5.83	0.14	1.7			
butane	58.123	120.98	0.05		1.42	2.34	0.16	0.8			
pentane+	72.15	148.84	0.02		0.04	1.18	0.41	0.5			
CO2	44.01	0	0.82	53.93	0.07	0.8	8.22				
H2S	34.076	23.7		0.01			35.79				
N2	28.013	0	0.68	0.21	21.14	1.39	2.53	25.6			
Mol wt:			16.62585	31.182	20.92126	21.28362	25.49289	20.44567			
heating value	MJ/M^3		37.6	17.3	34.9	46.8	30	30.7			
MJ/KG			50.65847	12.42768	37.36678	49.25478	26.36029	33.63451			
									avg	SD (rel)	
									19.61024	10.79%	
									39.76667	12.81%	
									45.76001	13.03%	

0.0224M^3/mol

too high too high too low
CO2 Sulfur heating
content for content value(?)
use

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
source Perry 6 (1984)
averaged from table 9-14

Btu/scf 1049.571

Synopsis of table 9-14

	Mwt	heat value MJ/M^3	Baltimore Md	Columbus Ohio	Houston Tx	Birmingham Al	Washington DC	Phoenix Az
mol%								
Methane	16.043	37.57	94.4	93.14	92.5	93.14	95.15	87.3
ethane	30.07	65.83	3.4	3.58	4.8	2.5	2.84	8.1
propane	44.097	93.6	0.6	0.66	2	0.67	0.63	2.2
butane	58.123	120.98	0.5	0.22	0.3	0.32	0.24	0.1
pentane+	72.15	148.84	0	0.09	0	0.12	0.05	0
CO2	44.01	0	0.6	0.85	0.27	1.06	0.62	0.6
H2S	34.076	23.7		0.01				
N2	28.013	0	0.5	0.21	21.14	2.14	0.42	1.3
Mol wt:			17.12629	16.93912	23.38022	17.32821	16.9628	18.1798

heating valMJ/M^3

MJ/KG

0.0224M^3/mol

39.2023	38.3444	38.4563	38.1952	38.83552	1.10%
51.27388	50.70597	36.84401	49.37455	48.12414	13.30%

Manufactured gas

Data from KO 2 (1964) for "modern mechanical method"				Gas		gas heat value				Tar data		
	Moisture	Heating valueBtu/lb		Gas yield scf/ton		gas lb/lb co	Gross heat value Btu/s		Btu/ton coa	Btu/lb coal	Tar yield gal/ton	
		wet	dry	wet base	dry base		wet base	dry base			wet base	wet base
Anthracite	0.051	10800	11380.4	123900	130558.5		138	145.4162	17098200	8549.1	9.5	10.01054
Belgian Co	0.026	11980	12299.79	120900	124127.3		150	154.0041	18135000	9067.5	1	1.026694
Baddeslev	0.05	12080	12715.79	116100	122210.5	3.581182	165.6	174.3158	19226160	9613.08	21	22.10526

On the basis of 10% tar production in the process the Baddesley type coal is used
This coal then provides 9613.08 gas heating value in Btu/lb coal

Baddesley coal ga

composition	MWt	vol%	O2 per mol	mol O2 per mol gas	
CO2	44.01	6.7	0	0	
alkyls					
O2	31.9988	0	0	0	
CO	28.016	25.3	0.5	0.1265	
H2	2.0158	21	0.5	0.105	
CH4	16.043	1.8	2	0.036	
N2	28.013	45.2	0	0	0.578864 mol air producing mol gas
Gas Mwt	23.41069		0.2675	mol O2 per mol gas	1.277093 mol air to burn mol gas
			0.365631	kg O2 per Kg gas	1.855957 mol air used/mol gas
			1.580041	kgair/kg gas	2.296221 kg air used / kg gas
ideal gas density of producer gas					
0.9882	kg/m^3				
0.061691	lb/s cuf		d=Mw/0.0224		

physical data

Density of T	75 lb/cuf	Perry 6 (1984)
	1200 kg/m^3	
	10.01449 lb/gal	

Units

scf is volume in cubic feet at 60 Farenheit and 30" Hg	KO 2 (1964)
288.7056 42.2115 0.02369	

density	lb/cuf	lb/gal	kg/m^3	Perry 6 (1984)
	0.062428	0.008345	1	
	7.480519	1	119.8264	
	1	0.133681	16.01846	

mass	ton (short - lb	kg	Perry 6 (1984)
	1	2000	
		2.204623	1

Pressure	"Hg	N/m^2	atm	psia	Perry 6 (1984)
	1	3376.9	0.033327	0.489775	
	2.041754	6894.8	0.068046	1	
	30.00533	101325	1	14.69586	
		1			

Heat value	MJ/m^3	btu/scf	Perry 6 (1984)
	0.0373	1	

Energy	MJ	Btu	Perry 6 (1984) for steam table values
	0.001055	1	

molar		kg air per kg		
dry air composition	Mwt	mass comp	component	
N2	0.78084	28.0134	0.75521	1.324134
O2	0.20946	31.9988	0.231406	4.321406
CO2	0.00033	44.01	0.000501	1994.319
Ar	0.00934	39.948	0.012882	77.62792
total	0.99997	28.96409	1	

Sheet Title: Nitroethane/nitromethane

Sheet Description: Nitroethane/nitromethane

Nitroethane is produced as a co-product in the production of nitroethane, nitromethane, 1-nitropropane, and 2-nitropropane

References/Citations: TRI inventory for 1991 for W. R. Grace Deer Park, Tx Facility

Personal communication from the plant manager of the Deer Park Facility to John Becker, Sept 6, 1995, indicating plant capacity for nitroparaffins at 20,000,000 lb/yr while operating. Plant closed in 1992.

Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed. 1978. v15. "Nitroparaffins

Summary Output:

Allocated LCI component	Units	Quantity	DQI
air emissions			
1,2-butylene lb/lb		0.0000006	2
2-nitropropan lb/lb		0.0005245	2
acetaldehyd lb/lb		6.065E-05	2
acetone lb/lb		0.0000407	2
acetonitrile lb/lb		0.0000209	2
ammonia lb/lb		0.0007652	2
BrClF2C lb/lb		0.0000019	2
BrF3C lb/lb		7.15E-06	2
Chlorine lb/lb		0.0000039	2
Cl2F2C lb/lb		0.00095	2
Formaldehyd lb/lb		0.0003096	2
Hydrogen cy lb/lb		5.555E-05	2
methanol lb/lb		1.635E-05	2
naphthalene lb/lb		0.0005544	2
nitric acid lb/lb		4.75E-06	2
water			
ammonia lb/lb		0.0000015	2
Hydrogen cy lb/lb		0.0000001	2
underground			
2-nitropropan lb/lb		0.0069671	2
acetaldehyd lb/lb		0.0089841	2
acetone lb/lb		0.0048216	2
acetonitrile lb/lb		0.0039334	2
ammonia lb/lb		0.0001229	2
Formaldehyd lb/lb		0.0000686	2
Hydrogen cy lb/lb		0.0000057	2
methanol lb/lb		0.0079189	2
naphthalene lb/lb		0.0000057	2
nitric acid lb/lb		0.0005548	2

Notes: The 4 co-products are produced as part of the same reaction.
Product percentage varies with operating conditions (Kirk-Othmer), but emissions must be considered on a lb/lb basis as 4 equal co-products.

Conversion Factors

Unit from	Unit to	Multiplier

Calculations

Table Title

Table Reference/Citation

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ put Std. Dev	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
air emissions							
1,2-butylene lb/yr		12			4 lb/lb	0.0000006	
2-nitropropan lb/yr		10490			4 lb/lb	0.0005245	
acetaldehydb lb/yr		1213			4 lb/lb	6.065E-05	
acetone lb/yr		814			4 lb/lb	0.0000407	
acetonitrile lb/yr		418			4 lb/lb	0.0000209	
ammonia lb/yr		15304			4 lb/lb	0.0007652	
BrClF2C lb/yr		38			4 lb/lb	0.0000019	
BrF3C lb/yr		143			4 lb/lb	7.15E-06	
Chlorine lb/yr		78			4 lb/lb	0.0000039	
Cl2F2C lb/yr		19000			4 lb/lb	0.00095	
Formaldehydb lb/yr		6192			4 lb/lb	0.0003096	
Hydrogen cylb/yr		1111			4 lb/lb	5.555E-05	
methanol lb/yr		327			4 lb/lb	1.635E-05	
naphthalene lb/yr		11087			4 lb/lb	0.0005544	
nitric acid lb/yr		95			4 lb/lb	4.75E-06	
water							
ammonia lb/yr		30			4 lb/lb	0.0000015	
Hydrogen cylb/yr		2			4 lb/lb	0.0000001	
underground							
2-nitropropan lb/yr		139342			4 lb/lb	0.0069671	
acetaldehydb lb/yr		179681			4 lb/lb	0.0089841	
acetone lb/yr		96431			4 lb/lb	0.0048216	
acetonitrile lb/yr		78668			4 lb/lb	0.0039334	
ammonia lb/yr		2457			4 lb/lb	0.0001229	
Formaldehydb lb/yr		1372			4 lb/lb	0.0000686	
Hydrogen cylb/yr		114			4 lb/lb	0.0000057	
methanol lb/yr		158377			4 lb/lb	0.0079189	
naphthalene lb/yr		114			4 lb/lb	0.0000057	
nitric acid lb/yr		11096			4 lb/lb	0.0005548	

Notes: Based on the information supplied by the plant manager of a production capacity of 20,000,000 lb/yr.

Sheet End =====

Nitric Acid+ Ammonium Nitrate

Source: all data

Technical report HDC-125-95 Pg 14

By Laurie J. Brown

Holston Defense Corporation

Subsidiary of Eastman Chemical Co.

Kingsport, TN 37660

Product	Conc.	Raw data in lb	kg per kg solution	kg per kg HNO3	kg per kg NH4NO3
Solution		1.356	1	1.7730496	2.3419204
HNO3	0.564		0.564	1	1.3208431
NH4NO3	0.427		0.427	0.7570922	1
W	0.009		0.009	0.0159574	0.0210773

Inputs

Materials

HNO3	0.99	1.233	0.909292	1.6122199	2.1294895
NH3		0.123	0.090708	0.1608297	0.2124308
Steam		0.02255	0.0166298	0.0294854	0.0389457
River Water		53.12	39.174041	69.45752	91.742485

Energy

Electricity	kWhr	0.02754	0.0203097	0.0360102	0.0475638

Waste

Water return to river (Non-contact)	53.12	39.174041	69.45752	91.742485

Steam Condensate to river (Non-contact)	0.02255	0.0166298	0.0294854	0.0389457

Air Emission

NOx (value is for NO2)	7.921E-06	5.841E-06	1.036E-05	1.368E-05

HNO3 Conc.

Nitric Acid concentration

Source: all data

Technical report HDC-125-95

Pg 12

By Laurie J. Brown

Holston Defense Corporation

Subsidiary of Eastman Chemical Co.

Kingsport, TN 37660

Product

	Conc. wt frac.	Raw data in lb	kg per kg solution	kg per kg HNO3
Solution		1.233	1	1.2454545
HNO3	0.99		0.99	1
W	0.01		0.01	0.010101

Output

to IWTF	water		0.8595	0.6970803	0.8681818
	NaNO3/w	0.904	0.01295	0.0105028	0.0130808
	NaNO3	as pure	0.0117068	0.0094946	0.0118251
	water	as pure	0.8607432	0.6980886	0.8694376
	Mg(NO3)2/w	0.6	0.009053	0.0073423	0.0091444

Inputs

Materials

HNO3	0.61	2.031	1.6472019	2.0515152
Na2CO3		0.007304	0.0059238	0.0073778
City Water		0.08226	0.0667153	0.0830909
MgO		0.001478	0.0011987	0.0014929
Steam		2.9	2.351987	2.9292929
River Water		28.81	23.365775	29.10101

Energy

Electricity	kWhr	0.05507	0.0446634	0.0556263

Waste

Water return to river (Non-contact)		28.81	23.365775	29.10101
Steam Condensate to river (Non-contact)		2.9	2.351987	2.9292929

Air Emission

NOx (value is for NO2)		0.003348	0.0027153	0.0033818

HNO3 Prod.

Nitric Acid production

Source: all data

Technical report HDC-125-95

Pg 10

By Laurie J. Brown

Holston Defense Corporation

Subsidiary of Eastman Chemical Co.

Kingsport, TN 37660

Product

		Conc. wt frac.	Raw data in lb	kg per kg solution	kg per kg HNO3
desired	Solution		2.031	1	3.3295082
	HNO3	0.61		0.61	1
	W	0.39		0.39	0.6393443

Output

					Oz troy	lb/Oz troy	(CRC '66)
to Cat recovery Plat Cat			2.715E-06		0.0000396	0.0685714	
	Pt	0.9		1.203E-06	4.006E-06		
	Pd	0.05		6.685E-08	2.226E-07		
	Rh	0.05		6.685E-08	2.226E-07		
to IWTF	NH3		3.691E-05	1.817E-05	6.051E-05		

Inputs

Materials

NH3		0.3353	0.1650911	0.5496721		
Air		6.53	3.2151649	10.704918		
City Water		0.4369	0.2151157	0.7162295		
Filtered Water		108.9	53.618907	178.52459		
Plat Cat		2.715E-06			Oz troy	lb/Oz troy
					0.0000396	0.0685714
Pt	0.9		1.203E-06	4.006E-06		
Pd	0.05		6.685E-08	2.226E-07		
Rh	0.05		6.685E-08	2.226E-07		
Steam		0.2293	0.1129	0.3759016		
River Water		54.42	26.794682	89.213115		

Energy

Electricity	kWhr	0.1926	0.0948301	0.3157377		

Waste

Water return to river (Non-contact)		163.3	80.403742	267.70492		
Steam Condensate to river (Non-contact)		0.2293	0.1129	0.3759016		

Air Emission

NOx (value is for NO2)		0.003348	0.0016484	0.0054885		

Nitric acid and Ammoniumnitrate synthesis

Area B Steam Plant

Source: for all data

Technical report HDC-125-95 Pg 26

By Laurie J. Brown

Holston Defense Corporation

Subsidiary of Eastman Chemical Co.

Kingsport, TN 37660

		Conc.	Raw data in lb	kg per kg Steam	kg per kg Steam		
Product	Steam		50.75	1	1		
				0.9230959		weighting	according to coal utilization
Output							
To Block Plant	Cinders		0.3436	0.0067704			
	Fly Ash		0.2655	0.0052315	0.0048292		
to IWTF	Boiler blowdown		1.269	0.0250049	0.0230819		
	with: Phosphates						
	Sulfates						
	Sulfites						
	Cooling Water		11.45	0.2256158	0.208265		
	with: fly ash						
	cinders						
Inputs							
Materials							
	Coal		5.037	0.0992512	0.0916184		
	Air		70.52	1.3895567	1.282694		
	Filtered Water		63.43	1.2498522	1.1537334		
	Boiler Guard		0.0002684	5.289E-06	4.882E-06	Anionic polymer surfactant "BoilerGUARD APG", Calgon	
	Conquor3475		9.305E-05	1.833E-06	1.692E-06	Diethylhydroxylamine, hydroquinone, Calgon	
	C-1 Antifoam		8.459E-06	1.667E-07	1.539E-07	Akoxyated alcohol solution, Calgon	
	Rock Salt		0.01196	0.0002357	0.0002175		
	Sulfuric acid		0.01408	0.0002774	0.0002561		
Energy							
	Electricity	kWhr	0.1756	0.0034601	0.003194		
Waste							
	Fly Ash to Landfill		0.3036	0.0059823	0.0055222		
Air Emission							
	VOCs		0.0001261	2.485E-06	2.294E-06		
	NOx		0.03451	0.00068	0.0006277		
	CO		0.01259	0.0002481	0.000229		
	SOx		0.09571	0.0018859	0.0017409		
	Particulates		0.001209	2.382E-05	2.199E-05		
	Flue gas		74.5	1.4679803	1.3550865		

Coal utilization breakdown for by product distribution

		lb/lb RDX
Coal	Coal	5.037
	Cinders	0.3436
	Ash	0.5691

Energy coal	4.1243	92.31%
Cinder Coal	0.3436	7.69%
Utilized coal	4.4679	100.00%

Nitric acid and Ammoniumnitrate synthesis

Area B Water filtration

Source: for all data

Technical report HDC-125-95 Pg 30

By Laurie J. Brown

Holston Defense Corporation

Subsidiary of Eastman Chemical Co.

Kingsport, TN 37660

		Conc.	Raw data in lb	kg per kg Filtered water
Product				
	Filtered water		560.2	1
Output				
to IWTF	with: Water		27.17	0.0485005
	Alum		0.1154	0.000206
	Filter backwash		67.56	0.1205998
	with:			
Inputs				
Materials				
	River water		655	1.1692253
	Hydrated lime		0.0008082	1.443E-06
	Al Sulfate		0.03795	6.774E-05
	Cl2		0.002547	4.547E-06
Energy				
	Electricity	kWhr	0.7422	0.0013249

Waste

Air Emission

Industrial Wastewater Treatment Facility

Both areas

Source: for all data

Technical report HDC-125-95 Pg 32

By Laurie J. Brown

Holston Defense Corporation

Subsidiary of Eastman Chemical Co.

Kingsport, TN 37660

		Conc.	Raw data in lb	kg per kg wastewater	
Product					
Output					
Inputs					
Materials					
IWTF streams	Wastewater		329.5	1	
	NaOH 20%		0.0314	9.53E-05	
	NaOH	0.2	0.00628	1.906E-05	
	water	0.8	0.02512	7.624E-05	
	Quicklime		0.002363	7.171E-06	
	FeCl2 25-35%		0.01109	3.366E-05	
	FeCl2	0.3	0.003327	1.01E-05	
	water	0.7	0.007763	2.356E-05	
	HCl 33%		0.0002453	7.445E-07	
	HCl	0.33	8.095E-05	2.457E-07	
	water	0.67	0.0001644	4.988E-07	
	Magnifloc 496		3.691E-05	1.12E-07	flocculant
	Filtered water		14.96	0.0454021	
Energy					
	Electricity	kWhr	0.2042	0.0006197	
Waste					
	Treated Industrial waste water				
			344.3	1.0449165	
landfill	Biological sludge		0.1533	0.0004653	
landfill	Alum Sludge		0.1154	0.0003502	

Air Emission

Sheet Title: Diisopropylidiazodicarboxylate (from dichlorodiazodialdehyde ClOCNNCOCl and isopropanol. It is a precursor in production of TNAZ)

Sheet Description: Emissions are from Engineering estimates, basic solvent is assumed to be pyridine at 2X excess and NOT recycled

Engineering calculation of the Energy requirements and precursor requirements.

Dichlorodiazodialdehyde manufacture from hydrazine and phosgene are included in the calculations

This page calculates the vendor emissions from a plant producing Diisopropylidiazodicarboxylate.

Not included are raw material production or extraction or water use.

References/Citations:

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)

US EPA

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11, 1994

Mwt	Co-product	Quantity	Units	Quantity	Units	1993 Production	
202.2096	Diisopropylidiazodicarb	1.00E+00	kg	1.00E+00	kg	17,859.00	88.3192489
	Total	1.00	Kg	1.00E+00	Kg	17,859.00	17859

dichlorodiazodialdehyde

Notes:

As acetone cyanohydrin

60

LCI components

Air	Unallocated		Allocated		Quantity	Std. Dev.	DQI
	Units	Quantity	Units	Quantity			
Phosgene	Kg/Kg Diazo	5.71092E-05	Kg/Kg Diazo	5.71092E-05	3		
Hydrazine	Kg/Kg Diazo	3.56014E-07	Kg/Kg Diazo	3.56014E-07	3		
Isopropanol	Kg/Kg Diazo	6.19977E-07	Kg/Kg Diazo	6.19977E-07	3		
Pyridine	Kg/Kg Diazo	5.58703E-06	Kg/Kg Diazo	5.58703E-06	3		
HCl	Kg/Kg Diazo	1.0474E-05	Kg/Kg Diazo	1.0474E-05	3		
Wastewater							
Phosgene	Kg/Kg Diazo	0.009783551	Kg/Kg Diazo	0.009783551	3		
Hydrazine	Kg/Kg Diazo	0.001584742	Kg/Kg Diazo	0.001584742	3		
Pyridine	Kg/Kg Diazo	2.347069575	Kg/Kg Diazo	2.347069575	3		
Pyridine HCl	Kg/Kg Diazo	3.428944026	Kg/Kg Diazo	3.428944026	3		

Resource Consumption

Phosgene	Kg/Kg Diazo	0.978355132	Kg/Kg Acetoni	0.978355132	3
Hydrazine	Kg/Kg Diazo	0.158474177	Kg/Kg Acetoni	0.158474177	3
Isopropanol	Kg/Kg Diazo	0.594389188	Kg/Kg Acetoni	0.594389188	3
Cl2	Kg/Kg Diazo	0.350655593	Kg/Kg Acetoni	0.350655593	3
Pyridine	Kg/Kg Diazo	4.694139151	Kg/Kg Acetoni	4.694139151	3

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors		Unit to	Multiplier	Reference
BTU	Wh	J	1055.056	CRC, 66th Edition
Wh	BTU	J	3600	CRC, 66th Edition
bbl CrO	bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.
bbl	gal	gal	42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed.
gal	L	L	3.785412	CRC, 66th Edition
kg	lb	lb	2.2046226	CRC, 66th Edition
yr	day	day	365	
m ³	bbl (petroleum)	bbl (petroleum)	6.289811	CRC, 66th Edition
gal CrO	lb CrO	lb CrO	7.2	
ton	lb	lb	2000	
gal fuel oil	BTU fuel oil	BTU fuel oil	138000	
cu. ft NG	BTU NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.
lb Coal (dry)	BTU Coal	BTU Coal	12000	calculation page B
kg NG	MJ NG	MJ NG	46	Calculation page C
			SD=11%	
			SD=13%	
Mw Benzen			78.1134	molar
Mw Chlorin			70.9	dry air composition
Mw ClBz			112.56	N2
Mw Cl2Bz			147.01	O2
Mw HCl			36.4609	CO2
Mw NaOH			39.9971	Ar
			total	0.99997
				28.96409
				1
				kg air per kg
				mass composition
				component
				1.324134
				0.75521
				0.231406
				0.000501
				0.012882
				77.62792
				1
				kg air per kg
				mass composition
				component
				1.324134
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				0.231406
				0.000501
				0.012882
				77.62792
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				0.000501
				0.012882
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				0.012882
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				mass composition
				component
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				0.75521
				0.231406
				0.000501
				0.012882
				77.62792
				1
				kg air per kg
				mass composition
				component
				1.324134
				0.75521

981.9 kg/m³ assumed volume in condenser is pyridine
0.004781 m³ 0.201801 mol gas

Phosgene	Kg/Kg Diazo	0	3 Kg/Kg Diazo	0
Hydrazine	Kg/Kg Diazo	0	3 Kg/Kg Diazo	0
Isopropanol	Kg/Kg Diazo	0	3 Kg/Kg Diazo	0
Cl2	Kg/Kg Diazo	0	3 Kg/Kg Diazo	0
Pyridine	Kg/Kg Diazo	0	3 Kg/Kg Diazo	0
Pyridine HCl	Kg/Kg Diazo	0	3 Kg/Kg Diazo	0

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ nput Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not inert)	Kg/Kg Diazo	0	0		5 Kg/Kg Diazo	0	0
Diazo	Kg/Kg Diazo	0	0		5 Kg/Kg Diazo	0	0
Pyridine	Kg/Kg Diazo	0	0		5 Kg/Kg Diazo	0	0
Heavy metals (Cadmium, Nickel, CKg/Kg Diazo	Kg/Kg Diazo	0	0		5 Kg/Kg Diazo	0	0

Deep well Injection

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ nput Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Diazo	Kg/Kg Diazo	0	0		Kg/Kg Diazo	0	0
Phosgene	Kg/Kg Diazo	0.009783551	0.009783551		Kg/Kg Diazo	0.009783551	0.009783551
Hydrazine	Kg/Kg Diazo	0.001584742	0.001584742		Kg/Kg Diazo	0.001584742	0.001584742
Pyridine	Kg/Kg Diazo	2.347069575	2.347069575		Kg/Kg Diazo	2.347069575	2.347069575
Pyridine HCl	Kg/Kg Diazo	3.428944026	3.428944026		Kg/Kg Diazo	3.428944026	3.428944026

Sheet Title: Phosgene (from chlorine and carbon monoxide. Phosgene is used in production of TNAZ precursor diisopropyldiazodicarboxylate)

Sheet Description: Emissions are from TRI database.
Engineering calculation of the Energy requirements and precursor requirements .
This page calculates the vendor emissions from a plant producing Phosgene.
Not included are raw material production or extraction or water use.

References/Citations: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th edSource for physical data and unit conversions
McGraw Hill, 1984

CRC Handbook of Chemistry and Physics, 66thSource for physical data and unit conversions

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

Summary Output

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

Mwt	Co-product	Quantity	Units	Quantity	Units	BP deg C	Sp G	Vapor density relative to air
98.92	Phosgene	1.00E+00	kg	1.00E+00	kg	8.2	1.392	3.4
Total		1.00E+00	Kg	1.00E+00	Kg			

Notes:

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
Cl2	Kg/kg Phosgen	1.41667E-05		Kg/kg Phosgen	1.41667E-05		5
CO	Kg/kg Phosgen	5.59634E-06		Kg/kg Phosgen	5.59634E-06		5
Phosgene	Kg/kg Phosgen	5.55556E-07		Kg/kg Phosgen	5.55556E-07		5

HCl Kg/kg Phosgen 5.55556E-07 Kg/kg Phosgen 5.55556E-07 5

Water**Solid Wastes****Resource Consumption**

CO Kg/kg Phosgen 0.23 Kg/kg Phosgen 0.23
 Cl2 Kg/kg Phosgen 0.72 Kg/kg Phosgen 0.72
 Activated Carbon/Kg/kg Phosgen 0.0005 Kg/kg Phosgen 0.0005

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference	
BTU	J	1055.056	CRC, 66th Edition	
Wh	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed.	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
m ³	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry)BTU Coal		12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%
Mw Benzen	78.1134	molar		
Mw Chlorin	70.9	dry air composition		
Mw ClBz	112.56	N2	0.78084	28.0134
Mw Cl2Bz	147.01	O2	0.20946	31.9988
Mw HCl	36.4609	CO2	0.00033	44.01
Mw NaOH	39.9971	Ar	0.00934	39.948
		total	0.99997	28.96409
				1

Ideal gas density at 15 C (60 F)

air (dry)

0.042296 mol/liter 42.29634021 mol/m³ 1.225075005 kg/m³

Calculations

Phosgene Production

1993

Source: None

Phosgene production capacity

SRI 1991 Directory of Chemical Producers, US

Mlb

2290

Utilization ratio:

chemical industry average 199

0.9

Capacity

Mlb

Calculated production:

Mlb

20

18

Van de Mark Chemical ComLockport, NY 14094

254

228.6

Olin Corporation Lake Charles, LA 70602

320

288

BASF Corporation Geismar, LA 70734

450

405

Miles Inc. Baytown TX 77520

Source: Emissions:

TRI database, 1993 data

The Van de Mark plant is the only manufacturer of phosgene for open sale on the market so only its TRI data are used

The following reported emissions were ascribed to Phosgene production

Phosgene

Chlorine

Carbon monoxideHCl

Van de Mark Chemical ComLockport, NY 14094 5.56E-07 1.42E-05 5.56E-07

Olin Corporation Lake Charles, LA 70602 1.71E-07 1.30E-04 2.42E-05

BASF Corporation Geismar, LA 70734 2.43E-08 7.29E-08 2.57E-04

Miles Inc. Baytown TX 77520 6.30E-07 1.98E-05 1.06E-05

1.133333333 1.394333512 9.84265E-06

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Fossil fuel (general)	MJ/kg Phosgen	0		MJ/kg Phosgene	0	
Coal	MJ/kg Phosgen	0		Kg/kg Phosgene	0	
Oil	MJ/kg Phosgen	0		Kg/kg Phosgene	0	
Natural Gas	MJ/kg Phosgen	0		Kg/kg Phosgene	0	
Hydropower	MJ/kg Phosgen	0				
Fission	MJ/kg Phosgen	0				
Electricity (generic)	MJ/kg Phosgen0.375737838			MJ/kg Phosgene	0.375737838	

Cooling water

25 deg C temp rise

0.104482 heat removal MJ/kg water 0.004179285 heat capacity MJ/Kg/deg C (see pCl3 sheet)

c water 0.263016 MJ/kg product 2.517333 Kg/Kg product 7.87E-05 kJ Elec/Kg 6224.3 D Hvap CC12Ocal/mol 0.263016316 MJ/Kg phosgene 0.375737595 Refrigeration electricity usage fo 0.7 efficiency

Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

condenser to storage Phosgene 1.392 1.5 MJ/kg Phosgen 1.6438E-07 viscosity is a guess
distillation to treatmentPhosgene solutio 1 1 Chlorine 7.8726E-08 viscosity is a guess

cooling water 1 1 2.517332912 2.43106E-07 total pumping energy per kg prod

Co-Products:

source: See from above

Resources: Faith, Keyes and Clark'e Industrial chemicals

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil	Kg/kg Phosgen	0			4 Kg/kg Phosgene	0	
Natural Gas	Kg/kg Phosgen	0			4 Kg/kg Phosgene	0	
Coal	Kg/kg Phosgen	0			4 Kg/kg Phosgene	0	
28.0104 CO	m^3/kg Phosge	0.23			4 Kg/kg Phosgene	0.23	
70.906 Cl2	Kg/kg Phosgen	0.72			4 Kg/kg Phosgene	0.72	
12.011 Activated Carbon	Kg/kg Phosgen	0.0005			4 Kg/kg Phosgene	0.0005	
Air	Kg/kg Phosgen	0			4 Kg/kg Phosgene	0	
Water	Kg/kg Phosgen	0			4 Kg/kg Phosgene	0	

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/kg Phosgen	0			Kg/kg Phosgene	0	
SOx	kg/kg Phosgen	0			Kg/kg Phosgene	0	
NOx	kg/kg Phosgen	0			Kg/kg Phosgene	0	
Cl2	kg/kg Phosgen	1.42E-05			Kg/kg Phosgene	1.41667E-05	
CO2	kg/kg Phosgen	0			3 Kg/kg Phosgene	0	
CO	kg/kg Phosgen	5.59634E-06			Kg/kg Phosgene	5.59634E-06	
Phosgene	kg/kg Phosgen	5.56E-07			Kg/kg Phosgene	5.55556E-07	
HCl	kg/kg Phosgen	5.56E-07			Kg/kg Phosgene	5.55556E-07	
HC total	kg/kg Phosgen	0			Kg/kg Phosgene	0	
Heavy meta(Cd+Ni+Cr)	kg/kg Phosgen	0			Kg/kg Phosgene	0	

Industrial practice is to leave excess

Water

Raw/	Raw/	Raw/	Transformed	Transformed

LCI component	Input Units	Input Quan.	Input Std. Dev.	DQI	Units	Quan.	Std. Dev.
COD	kg/kg Phosgen	0			5 Kg/kg Phosgene	0	
BOD	kg/kg Phosgen	0			5 Kg/kg Phosgene	0	
Acid, H+ (Phosphoric)	kg/kg Phosgen	0			5 Kg/kg Phosgene	0	
Metal ions	kg/kg Phosgen	0			5 Kg/kg Phosgene	0	
Cl2	kg/kg Phosgen	0			5 Kg/kg Phosgene	0	
CO2	kg/kg Phosgen	0			5 Kg/kg Phosgene	0	
CO	kg/kg Phosgen	0			5 Kg/kg Phosgene	0	
Phosgene	kg/kg Phosgen	0			5 Kg/kg Phosgene	0	
HCl	kg/kg Phosgen	0			5 Kg/kg Phosgene	0	
Heavy metals (Cadmium, Ni/kg/kg Phosgen		0			5 Kg/kg Phosgene	0	

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not inert)	kg/kg Phosgen	0			5 Kg/kg Phosgene	0	
Heavy metals (Cadmium, Ni/kg/kg Phosgen		0			5 Kg/kg Phosgene	0	

Sheet End

Sheet Title: Ammonia (data for fertilizer production, applied to nitric acid production)

Sheet Description: This page calculates the vendor-independent emissions from US plants producing fertilizer quality Ammonia. Oil and Natural gas extraction and transportation are not included.

References/Citations:

U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.1-1.

Energy Information Administration. 1994. Manufacturing Consumption of Energy. 1991, DOE/EIA 0512(91).

United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors, AP-42.

United States Department of Energy. Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

United States Department of Energy. Energy Information Administration. 1993. Annual Energy Review. 1993, DOE/EIA-0384(93).

Summary Output

Co-product Allocation Calculations				
	Co-product	Quantity	Units	
	Ammonia	1.00E+00	kg	
	Total	1	kg	

LCI components	Allocated			
	Unallocated	Quantity	Std. Dev.	Quantity
Air	TSP (PM-10)	5.90939E-10		kg/Kg TNAAZ
	SOx	2.88E-05		kg/Kg TNAAZ
	NOx	6.13238E-09		kg/Kg TNAAZ
	CO	0.007900001		kg/Kg TNAAZ
	CO2	1.2234		kg/Kg TNAAZ
	Ammonia	0.0021		kg/Kg TNAAZ
	Methane	7.47036E-10		kg/Kg TNAAZ
	other organic	0.004720003		kg/Kg TNAAZ
	Water			
	Solid Wastes			

Resource Consumption			
fuel	Natural Gas	0.549481458	
	Natural Gas	0.5057511	
	Electric Power	1.1	
	steam	0.38	

Notes: Bbl eq. are calculated on a energy content basis and used to calculate the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Table 35 Process Related Emissions from Ammonia Manufacture for Nitrogenous Fertilizers
U.S. EPA, 1995, AP-42, Fifth Edition, Table 8.1-1.

Emission Source	CO	lb/ton of ammonia produced SO ₂	NH ₃	CO ₂	Total Organic Compounds
Desulfurization Unit	13.8	0.0576			7.2
Carbon Dioxide Regenerator	2		2	2,440	1.04
Condensate Steam Stripper			2.2	6.8	1.2
Total	15.8	0.0576	4.2	2446.8	9.44
In units of	Kg/Kg ammonia				
Total	0.0079	0.0000288	0.0021	1.2234	0.00472

Notes: Since we know the amount of methane (and hence carbon) used as a feedstock for Ammonia production one can calculate a bound on process related CO₂ emissions.

Feedstock Methane Use	21.78 million btu/ton ammonia	0.024008094 million btu/kg ammonia
	26.48222965 million btu/ton N	1.055232558 kg/ kg Ammonia
	13241.11482 Btu/lb N	
Carbon per unit Methane	14.47 Million metric tons C/quad	
	31.900562 lb C/million btu	
	116.8876325 lb CO ₂ /million btu	
	1.547722563 lb CO ₂ /lb N	
	3095.445126 lb CO ₂ /ton N	

This shows that the CO₂ emission factors for process related emissions are based on the carbon value of the feedstock, and the assumption that virtually all carbon is emitted, not used for other purposes.

Emissions from Energy Consumption in Ammonia Manufacture

Energy Information Administration, 1994, Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

United States Environmental Protection Agency, 1995, Compilation of Air Pollutant Emission Factors, AP-42.

United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

Energy for Nonfuel Purposes (MECS Table A3)

Nitrogenous Fertilizers	Raw Input Quantity	Units	Transformed Input Quantity	Units	Notes:
Natural Gas	289	Tbtu	52.07%	Feedstock Share	
Total	290	Tbtu			

Energy for Heat, Power, etc. (MECS Table A4)

Natural Gas	266	Tbtu	0.479279279	Fuel Share	
Electricity	10	Tbtu			
Other	4	Tbtu			

Total Primary Energy Consumption (MECS Table A1)

Natural Gas	555	Tbtu			
Electricity	10	Tbtu			
Other	568	Tbtu			

Large Industrial Boiler Emission Factors (AP-42, Tables 1.4-1 to 1.4-3)

Natural gas powered heat source

SO2	0.6	lb/million cubic ft	0.00058	lb/million bu	
NOx	550	lb/million cubic ft	0.53295	lb/million bu	
Uncontrolled	81	lb/million cubic ft	0.07849	lb/million bu	
Controlled-Lo NOx	53	lb/million cubic ft	0.05136	lb/million bu	
Controlled-FGR	67	lb/million cubic ft	0.06492	lb/million bu	
Average Controlle	308.5	lb/million cubic ft	0.29893	lb/million bu	
Average	40	lb/million cubic ft	0.03876	lb/million bu	
CO	13.7	lb/million cubic ft	0.01328	lb/million bu	
PM-10	0.289	lb/million cubic ft	0.00028	lb/million bu	
Methane	1.41	lb/million cubic ft	0.00137	lb/million bu	
Non-methane VOC's	14.47	million metric ton	116.9	lb/million bu	
CO2					
Heat Content of Natural Gas (AER, Table A	1,032	Btu/cubic foot			

This factor is given as the sum of filterable and condensible particulate. All PM emissions from N.G. consumption are thought to be < 10 microns in diameter

Emissions from the Use of N.G. in the Manufacture of Ammonia

SO2	6.69E-12	kg/kg ammonia			
NOx	6.13E-09	kg/kg ammonia			
CO	9.03E-10	kg/kg ammonia			
PM-10	5.91E-10	kg/kg ammonia			
Methane	7.47E-10	kg/kg ammonia			
Non-methane VOC's	3.44E-09	kg/kg ammonia			
CO2	4.46E-10	kg/kg ammonia			

Notes: The share of N.G. used as feedstock for Ammonia vs. fuel is used to reduce emissions estimates to account for N.G. not consumed in boilers.

Emission factors are converted into units of lb/million btu, which are multiplied by energy consumption and share of energy used as fuel. Emissions from the consumption of electricity by the industry will be calculated by the electricity module.

N.G. is used as a feedstock through a reforming process to produce hydrogen gas. This is the predominant process for ammonia production in the U.S. The hydrogen is reacted with nitrogen to form ammonia. This process results in the production of carbon dioxide and carbon monoxide. Carbon monoxide can be converted back to carbon dioxide through the water-gas shift reaction. Carbon dioxide has industrial use in several areas including the manufacture of urea from ammonia, but some carbon dioxide is emitted from the process. These and other process related emissions are treated in Table 25.

Source:

Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangilo, 1993. Energy Use in Synthetic Agricultural Inputs: Revised, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

Energy Requirements for Fertilizer Production

Anhydrous Ammonia	Natural Gas	Electricity	Oil	Steam	Exported Steam	Total
	40.79	1.1		0	0.38	41.51 (GJ/metric ton)
	38693.394	1043.46		0	0	39376.386 Btu/kg
	kg/kg Ammonia	MJ/kg Ammonia				
	17.00698487	1.1				

Notes: Taken from Table 16 (p. 26).

Source:

Unit from	Unit to	Multiplier	Name	Source
bu	lb	56	lb_bu	
Hectares	acre	2.471	acre_hect	
Kg	lb	2.2046	lb_kg	
Hectares	sq. meters	10,000	sqmeters_hect	
meter	feet	3.281	feet_meter	
short tons	lb	2000	lb_shortton	
metric tons	kg	1000	kg_mton	
kcal	btu	3.968	btu_kcal	
Joules	btu	9.48E-04	btu_joule	
Gallons Ethanol	lb	6.6	lb_gallon	
Gallons Ethanol	bu	0.4	bu_gallon	
Hectares	Sq. cm	1.00E+08	sqcm_ha	
cubic cm	liters	0.001	liters_ccm	
liters	gallons	0.264	gallons_liter	
sq mile	acres	640	acres_sqmile	
metric tons	short tons	1.102	shortton_metricton	
barrels	gallons	42	gallons_barrel	0
kg	grams	1,000	grams_kg	0
cubic foot natural gas	btu	1,032	btu_cubict	0
barrel distillate fuel	million btu	5,825	btu_barreloil	0
barrel motor gas	million btu	5,253	btu_barrelgas	0
Short ton coal	million btu	22.25	Btu_toncoal	0
Barrel LPG	million btu	3,614	Btu_barrelpg	86,048

Molecular Wts.

H	1.008
Ca	40.08
O	16.00
S	32.06
C	12.01
Cl	35.45
K	39.10
P	30.97
N	14.01
K2O	94.20
KCl	74.56
CO2	44.01
CaSO4	136.14
H2SO4	98.07
P2O5	141.94
HNO3	63.01
NH4NO3	80.04

Sheet Title: soda caustic

Sheet Description: This page calculates the vendor-independent emissions from european manufacture of caustic soda .

References/Citations: SimaPro3 (entry of Nov 18 94)
Average european data for NaOH/Cl₂ producers.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 6, tbi 15 pg 13 and report 5 (allocation)

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units
NaOH	1.00E+00	Kg
Chlorine		data after allocation
Total		1 Kg

LCI components	Unallocated	Quantity	Std. Dev.	Allocated	Quantity	Std. Dev.	DQI
	Units			Units			
Air							
COD	Kg/Kg soda caus	0.074					3
BOD	Kg/Kg soda caus	0.00002					3
Acid as H ⁺	Kg/Kg soda caus	0.007					3
Nitrate	Kg/Kg soda caus	0.0008					3
Metal ions	Kg/Kg soda caus	1.21					3
Cl ₂	Kg/Kg soda caus	0					3
ammonia	Kg/Kg soda caus	0.00018					3
dissolved organi	Kg/Kg soda caus	0.006					3
Crude	Kg/Kg soda caus	0.000002					3
dissolved subst	Kg/Kg soda caus	0.00005					3
HC's	Kg/Kg soda caus	0					
unknown (N)	Kg/Kg soda caus	0.0028					
Water							
COD	Kg/Kg soda caus	0.00001					3
BOD	Kg/Kg soda caus	0.000003					3
Acid as H ⁺	Kg/Kg soda caus	0.00034					3
Metal ions	Kg/Kg soda caus	0.00009					3

Cl2	Kg/Kg soda caus	0.042	3
Dissolved Organ	Kg/Kg soda caus	0	3
suspended solid	Kg/Kg soda caus	0.002	3
crude oil	Kg/Kg soda caus	0	3
miscellaneous dis	Kg/Kg soda caus	0.00005	3
total HC's	Kg/Kg soda caus	0	3
sodium	Kg/Kg soda caus	0.0028	3
Solid Wastes			
Production waste	Kg/Kg soda caus	0.099	3
Resource Consumption			
Natural Gas	Kg/Kg soda caus	0.176505121	3
Crude Oil	Kg/Kg soda caus	0.129783177	3
Coal	Kg/Kg soda caus	0	3
Coal	MJ/Kg soda caus	0.217294119	3
Hydropower	MJ/Kg soda caus	0.734851726	3
Fission		5.940913952	
Iron ore	Kg/Kg soda caus	0.00046	
limestone	Kg/Kg soda caus	0.0105	
Rock salt	Kg/Kg soda caus	0.59	
Water	Kg/Kg soda caus	5.3	
sand		0.00002	
fuel		6766029.629	
fuel		23.09245495	
fuel		38.66336743	

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors		Multiplier	
Unit from	Unit to	1055,056	Reference
BTU	J	3600	CRC, 66th Edition
Wh	J	5800000	CRC, 66th Edition
bbl CrO	BTU CrO	42	Chemical Engineers' Handbook, 6th ed.
bbl	gal	118500	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	3,785412	Chemical Engineers' Handbook, 6th ed.
gal	L	2,2046226	CRC, 66th Edition
kg	lb	365	CRC, 66th Edition
yr	day	6,289811	
m^3	bbl (petroleum)	7.2	CRC, 66th Edition
gal CrO	lb CrO	2000	
ton	lb	138000	
gal fuel oil	BTU fuel oil	1032	

Figure 9-4 @ S.G. = .76 and sulfur = 0.5%

cu. ft NG BTU NG 12000 Chemical Engineers' Handbook, 6th ed.
 lb Coal (dry) BTU Coal 46 calculation page B SD=11%
 kg NG MJ NG ----- Calculated page C SD=13%

Calculations

Ethylene Production

	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
LCI component	1 Kg						
soda caustic (polymer)							
soda caustic (other)				3			

SimaPro3

0

Average data for 19 european cracking facilities producing monomer quality soda caustic.

taken from:

PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994

report 2, tbl 36 pg 21

Energy input

	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
LCI component	MJ/Kg soda caus						
Coal	MJ/Kg soda caus	5.86			3 Kg/Kg soda caustic	0.217294119	
Oil	MJ/Kg soda caus	3.5			3 Kg/Kg soda caustic	0.129783177	
Natural Gas	MJ/Kg soda caus	4.76			3 Kg/Kg soda caustic	0.176505121	
Hydropower	MJ/Kg soda caus	0.71			3 MJ/Kg soda caustic	0.734851726	
Fission	MJ/Kg soda caus	5.74			3 MJ/Kg soda caustic	5.940913952	
unspecified		0.72					

Probably different mix in US

Material input

	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
LCI component	MJ/Kg soda caus						
Oil	MJ/Kg soda caus	0			3 Kg/Kg soda caustic	0	
Natural Gas	MJ/Kg soda caus	0			3 Kg/Kg soda caustic	0	
Coal	Kg/Kg soda caus	0			3 Kg/Kg soda caustic	0	
Iron ore	Kg/Kg soda caus	0.00046			3 Kg/Kg soda caustic	0.00046	
limestone	Kg/Kg soda caus	0.0105			3 Kg/Kg soda caustic	0.0105	
Bauxite	Kg/Kg soda caus	0			3 Kg/Kg soda caustic	0	
Rock salt	Kg/Kg soda caus	0.59			3 Kg/Kg soda caustic	0.59	
Clay	Kg/Kg soda caus	0			3 Kg/Kg soda caustic	0	
Water	Kg/Kg soda caus	5.3			3 Kg/Kg soda caustic	5.3	
sand	Kg/Kg soda caus	0.00002			3 Kg/Kg soda caustic	0.00002	

Output

	Raw/ Input Units	Raw/ Input Std. Dev.	Transformed	Transformed
Air				

LCI component	Kg/Kg soda caus	Input Quan.	Input Std. Dev.	DQI	Units	Quan.	Std. Dev.
TSP	Kg/Kg soda caus	0.074			Kg/Kg soda caustic	0.074	
SOx	Kg/Kg soda caus	0.00002			Kg/Kg soda caustic	0.00002	
NOx	Kg/Kg soda caus	0.007			Kg/Kg soda caustic	0.007	
CO	Kg/Kg soda caus	0.0008			Kg/Kg soda caustic	0.0008	
CO2	Kg/Kg soda caus	1.21			Kg/Kg soda caustic	1.21	
H2S	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
HCl	Kg/Kg soda caus	0.00018			Kg/Kg soda caustic	0.00018	
total HC's		0.006			Kg/Kg soda caustic	0.006	
Heavy metals	Kg/Kg soda caustic	0.000002			Kg/Kg soda caustic	0.000002	

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg soda caus	0.00001			Kg/Kg soda caustic	0.00001	
BOD	Kg/Kg soda caus	0.000003			Kg/Kg soda caustic	0.000003	
Acid as H+	Kg/Kg soda caus	0.00034			Kg/Kg soda caustic	0.00034	
Nitrate	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
Metal ions	Kg/Kg soda caus	0.00009			Kg/Kg soda caustic	0.00009	
Cl2	Kg/Kg soda caus	0.042			Kg/Kg soda caustic	0.042	
ammonia	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
dissolved organics	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
suspended particles	Kg/Kg soda caus	0.002			Kg/Kg soda caustic	0.002	
Crude	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
dissolved substances	Kg/Kg soda caus	0.00005			Kg/Kg soda caustic	0.00005	
HC's	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
sodium	Kg/Kg soda caus	0.0028			Kg/Kg soda caustic	0.0028	
Solid waste	Kg/Kg soda caus						
Production waste (not inert)	Kg/Kg soda caus	0.099			Kg/Kg soda caustic	0.099	
Toxic chemicals		0.00002			Kg/Kg soda caustic	0.000001	

CrO from Alaska	1000 bbl/day	1798	ton/yr	99228024
Total			ton/yr	99228024
Water Shipping - Lower 48	mi	0	ton-mi/yr	0
Water Shipping - Alaska	mi	2439.6	ton-mi/yr	2.42077E+11

Crude Oil Transport									
Association of Oil Pipe Lines Data for 1990									
	Raw/								
LCI component	Input Units	Raw/	Raw/						
Pipelines	mi	Input Quan.	Input Std. Dev.	DQI	Transformed	Transformed	Transformed		
Water	mi	0			Units	Quan.	Std. Dev.		
Highway/Motor Carrier	mi	2439.6							
Rail	mi	1000							
		697							
LCI component	Raw/								
Pipelines	Input Units	Raw/	Raw/						
Water	BTU/ton-mi	Input Quan.	Input Std. Dev.	DQI	Transformed	Transformed	Transformed		
	BTU/ton-mi	0			Units	Quan.	Std. Dev.		
	BTU/ton-mi	361			gal fuel/bbl CrO	0.964936049			

Highway/Motor Carrier	BTU/ton-mi	434	gal fuel/bbl CrO	0.553762025
Rail		434	gal fuel/bbl CrO	0.385972132

Water Transport Emissions

LCI component	Raw/		DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	Input Units	Input Quan.				
SOx	lb/1000 gal fuel	27		kg/bbl CrO	0.011817566	
CO	lb/1000 gal fuel	100		kg/bbl CrO	0.043768763	
HC	lb/1000 gal fuel	50		kg/bbl CrO	0.021884382	
NOx	lb/1000 gal fuel	280		kg/bbl CrO	0.122552537	
HC - transfer	lb/1000 gal hauled	0.97		kg/bbl CrO	0.018479353	

Highway Transport Emissions

LCI component	Raw/		DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	Input Units	Input Quan.				
HC	lb/1000 gal fuel	5.4572		kg/bbl CrO	0.001370752	
CO	lb/1000 gal fuel	15.3321		kg/bbl CrO	0.003851151	
NOx	lb/1000 gal fuel	18.6622		kg/bbl CrO	0.004687613	
HC - transfer	lb/1000 gal hauled	3.25		kg/bbl CrO	0.061915359	

Railroad Transport Emissions

LCI component	Raw/		DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	Input Units	Input Quan.				
TSP	lb/1000 gal fuel	25		kg/bbl CrO	0.00437685	
SOx	lb/1000 gal fuel	57		kg/bbl CrO	0.009979219	
CO	lb/1000 gal fuel	130		kg/bbl CrO	0.022759622	
HC	lb/1000 gal fuel	94		kg/bbl CrO	0.016456957	
NOx	lb/1000 gal fuel	370		kg/bbl CrO	0.064777386	
Aldehydes	lb/1000 gal fuel	5.5		kg/bbl CrO	0.000962907	
Organic Acids	lb/1000 gal fuel	7		kg/bbl CrO	0.001225518	
HC - transfer	lb/1000 gal hauled	3.25		kg/bbl CrO	0.061915359	

Sheet End

Sheet Title: Sulfuric Acid (for phosphate wet method production)

Sheet Description: This page calculates the vendor-independent emissions from domestic production of sulfuric acid. Oil extraction and transportation are not included

References/Citations: U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.8-1.
The Fertilizer Institute. 1982. The Fertilizer Handbook

Summary Output

Co-product Allocation Calculations			
Co-product	Quantity	Units	
H2SO4	1.00E+00	Kg	
Total	1	Kg	

Notes: Bbl eq. are calculated on a energy content basis and used to calculate the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

LCI components	Unallocated		Allocated		Std. Dev.	Quantity	DQI
	Units	Quantity	Units	Quantity			
Air							
SOx	Kg/Kg Sulfuric	0.013					4
CO2	Kg/Kg Sulfuric	0.00405					4
H2SO4	Kg/Kg Sulfuric	0.000064					4
Water							
Solid Wastes							
Resource Consumption							

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Process Emissions from Sulfuric Acid Manufacture (data for phosphoric acid manufacture, applied to general use: HNO3, ion exchange etc.)

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.8-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Sulfuric acid is used in the manufacture of many precursors to TNAAZ. Emission consist primarily of sulfur dioxide and acid mist. Sulfur dioxide emissions are primarily a function of the conversion efficiency from SO2 to SO3 in the plant.

Emission Factors

Conversion Factors		Multiplier		Name		Source:	
Unit from	Unit to						
bu	lb	56	lb_bu				
Hectares	acre	2.471	acre_hect				
kg	lb	2.2046	lb_kg				
hectares	sq. meters	10,000	sqmeters_hect				
meter	feet	3.281	feet_meter				
short tons	lb	2000	lb_shortton				
metric tons	kg	1000	kg_mton				
kcal	btu	3.968	btu_kcal				
Joules	btu	9.49E-04	btu_joule				
Gallons Ethalb	6.6 lb_gallon						
Gallons Ethabu	0.4 bu_gallon						
Hectares	Sq. cm	1.00E+08	sqcm_ha				
cubic cm	liters	0.001	liters_ccm				
liters	gallons	0.264	gallons_liter				
sq mile	acres	640	acres_sqmile				
metric tons	short tons	1.102	shortton_metricton				
barrels	gallons	42	gallons_barre				0
kg	grams	1,000	grams_kg				
cubic foot nabitu	1.032 btu_cubict						0
barrel distilla million btu	5.825 btu_barrelol						138,690
barrel motor million btu	5.253 btu_barrelga						0
Short ton coamillion btu	22.25 Btu_toncoal						0
Barrel LPG	million btu	3.614	Btu_barrelpg				86,048
Molecular Wts.							
H		1.008					
O		16.00					
Cl		35.45					
K		39.10					
CO2		#REF!					
CaSO4		#REF!					

Conversion Eff. - SO2 -> SO3	SO2 Emissions lb/ton sulfuric acid	kg/kg sulfuric acid
93	96	0.048
94	82	0.041
95	70	0.035
96	55	0.0275
97	40	0.02
98	26	0.013
99	14	0.007
99.5	7	0.0035
99.7	4	0.002
100	0	0

Notes: Sulfur dioxide emissions are highly correlated with conversion efficiency. Typical conversion efficiencies are given in AP-42 as 95 to 98%. Sulfur emissions can be controlled using standard sulfur capture technologies. New Source Performance Standards are also set quite low, at 4 lb/ton of product. Assuming that new plants comply with NSPS limits, but that old plants exist with higher emissions, the emission rate used here is at the upper end of conversion efficiency estimates.

Acid Mist Emission Factors (Where values are given as a range, the midrange is used)

Raw Material	lb/ton H2SO4	kg/kg Sulfuric acid
Recovered Sulfur	Uncontrolled 0.574	Uncontrolled 0.000287
Elemental Sulfur	Controlled -	Controlled -
Bright Virgin Sulfur	1.7	0.00064
Dark Virgin Sulfur	3.3	0.00085
Spent Acid	2.3	2.08
		0.00165
		0.00115
		0.0017

Notes: According to AP-42 about 81% of sulfuric acid production is from elemental sulfur burning. Average emission factors are calculated above using the elemental, bright virgin, and dark virgin sulfur factors. The uncontrolled and controlled factors are then averaged.

Carbon Dioxide 8.1 lb/ton sulfuric acid
0.00405 kg/kg Sulfuric acid

Notes: Carbon dioxide emissions are negligible relative to other sources and are thus neglected.

Sheet Title: Chlorobenzenes (mono- for triphenyl posphine production)

Sheet Description: Emissions are from TRI database.
Engineering calculation (rough) of the Energy requirements based on the cooling and distillation needs.
This page calculates the vendor emissions from a plant producing Chlorobenzenes.
Not included are raw material production or extraction or water and energy use.

References/Citations: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

Kirk Othmer Encyclopaedia of Chemical Technology
2nd ED, 1964 and 4th Ed. 1991-4
Wiley Interscience,

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

Mwt	Co-product	Quantity	Units	Quantity	Units
112.559	Chlorobenzene	8.85E+07	kg	1.72E+00	kg
	Not as precursor:	5.15E+07	kg	1.00E+00	kg
147.091	o-dichlorobenzen	15767000	kg	3.06E-01	kg
					derivative of mono-chlorobenzene

Chlorobenzene

147.091	p-dichlorobenzen	32614000	kg	6.34E-01	kg	derivative of mono-chlorobenzene
	trichlorobenzenes		kg			
36.4609	HCl	40660216.8	kg	7.90E-01	Kg	Product of chlorination
Total		1.41E+08	Kg	2.73E+00	Kg	

Notes:

LCI components		Unallocated		Allocated		DQI
	Units	Quantity	Std. Dev.	Units	Quantity	
Air						
Cl2	Kg/Kg Chlorob	0.004199242		Kg/Kg Chlorob	0.002442546	3
Benzene	Kg/Kg Chlorob	5.32399E-06		Kg/Kg Chlorob	3.09677E-06	3
HCl	Kg/Kg Chlorob	0.0072757		Kg/Kg Chlorob	0.004232035	3
dichlorobenzenes	Kg/Kg Chlorob	4.31031E-06		Kg/Kg Chlorob	2.50715E-06	3
chlorobenzene	Kg/Kg Chlorob	7.01061E-05		Kg/Kg Chlorob	4.07782E-05	3
Water						
Solid Wastes						
Resource Consumption						
Heat Energy (fos	MJ/Kg Chlorob	4.396342073		MJ/Kg Chlorob	4.396342073	
Electric Power	MJ/Kg Chlorob	2.361E-05		MJ/Kg Chlorob	2.361E-05	
Benzene	Kg/Kg Chlorob	0.693971215		Kg/Kg Chlorob	0.693971215	
Chlorine	Kg/Kg Chlorob	0.629886283		Kg/Kg Chlorob	0.629886283	
Sodium hydroxid	Kg/Kg Chlorob	0.008664743		Kg/Kg Chlorob	0.008664743	

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference
BTU	J	1055.056	CRC, 66th Edition
Wh	J	3600	CRC, 66th Edition

bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.
bbl gal		42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%
gal L		3.785412	CRC, 66th Edition
kg lb		2.2046226	CRC, 66th Edition
yr day		365	
m ³	bbl (petroleum)	6.289811	CRC, 66th Edition
gal CrO	lb CrO	7.2	
ton lb		2000	
gal fuel oil	BTU fuel oil	138000	
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.
lb Coal (dry) BTU Coal		12000	calculation page B SD=11%
kg NG MJ NG		46	Calculated page C SD=13%

Mw Benzen	78.1134	molar	dry air composition	Mwt	mass composition component	kg air per kg
Mw Chlorin	70.9		N2	0.78084	28.0134	0.75521
Mw ClBz	112.56		O2	0.20946	31.9988	0.231406
Mw Cl2Bz	147.01		CO2	0.00033	44.01	0.000501
Mw HCl	36.4609		Ar	0.00934	39.948	0.012882
Mw NaOH	39.9971		total	0.99997	28.96409	1

Ideal gas density at 15 C (60 F) air (dry)
 0.042296 mol/liter 42.29634021 mol/m³ 1.225075005 kg/m³

Calculations

Chlorobenzene Production

Energy input

All energy is assumed to come from the heat of combustion in the formation of CO, which is recoverable.

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Fossil fuel (general)	MJ/kg Chlorobe	4.396342073				0.157507219	
Coal	MJ/kg Chlorobe	0			kg/kg Chlorobenze	0	
Oil	MJ/kg Chlorobe	0	15		kg/kg Chlorobenze	0	0.33622909
Natural Gas	MJ/kg Chlorobe	0			kg/kg Chlorobenze	0	
Hydropower	MJ/kg Chlorobe	0					
Fission	MJ/kg Chlorobe	0					

Electricity (generic) MJ/kg Chlorob 2.361E-05
Probably different mix in US

Material input

Source: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Benzene batch Chlorination method (Cl₂ bubbled through)

from Faith Keyes and Clark's Industrial chemicals, 1975

Stoichiometric ratios:

Benzene net	Kg/Kg Chlorob	0.693971215	100% conversion of Benzene
Cl ₂ net	Kg/Kg Chlorob	0.629886283	
Benzene input	Kg/Kg Chlorob	0.693971215	100% conversion of Benzene
Cl ₂ input - no recycle	Kg/Kg Chlorob	1.049810471	60% conversion of Cl ₂
Chlorine input	Kg/Kg Chlorob	0.634085525	99% Cl ₂ recovery - assumed, because of bubbling apparatus

Emission calculation

Air			
Cl ₂ released from process	Kg/Kg Chlorob	0.004199242	1% Unconverted Cl ₂
HCl released	Kg/Kg Chlorob	0.0072757	released in scrubber vent see calculation
CO ₂	Kg/Kg Chlorob	0	
Particulates	Kg/Kg Chlorob	0	
Benzene	Kg/Kg Chlorob	5.32399E-06	open neutralizer vent
mono Chlorobenzene	Kg/Kg Chlorob	7.01061E-05	
o dichlorobenzene	Kg/Kg Chlorob	4.31031E-06	
p dichlorobenzene	Kg/Kg Chlorob	0	
SO _x	Kg/Kg Chlorob	0	
NO _x	Kg/Kg Chlorob	0	
Heavy metals	Kg/Kg Chlorob	0	

HCl emission calculation

Vapor pressure of 1mmHg over water solution 20%
Open scrubber assumed to equilibrate so that vapor containing 1/760 parts volume HCl is displaced from the scrubbing chamber by the incoming water/HCl stream
20% HCl
7.90E-01 Kg HCl produced/Kg Chlorobenzene

Chlorobenzene

HCl sol. density kg/m³(roug 1100 3.949340383 Kg HCl stream
HCl partial pressure mmHg 1 CRC 66 0.0072757 Kg HCl (1/760)
Overall pressure (atm) mmH 761 CRC 66

Benzene Emissions calculation

Vapor pressure at condenser vent assumed to be at 25 degC

Composition (mol%)	wt%				Raoult's law vapor composition	Kg emission/Kg prod
Bz 99% con	78.11	0.01 0.781134	0.006315964 Bz	100 mmHg	0.00131406	5.32E-06
ClBz	112.56	0.7 78.792	0.637083303 ClBz	13.05454545 mmHg	0.012008123	7.01E-05
Cl2Bz-o	147.01	0.2 29.402	0.237733822 Cl2Bz-o	2.150895141 mmHg	0.000565281	4.31E-06
Cl2Bz-p	147.01	0.1 14.701	0.118866911 Cl2Bz-p solid a	0 mmHg	0	0
Source: FKC 75 4ed		123.676134	CRC 66 interpolated			

vapor displacement by chlorobenzine product/kg mono ClB 0.00122629 m³ 0.051867653 mol gas displaced/kg ClBz
density of ClBz at end of react 1,280.00 kg/m³

Co-Products:

source: See from above

Resources:

LCL component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil					Kg/Kg Chlorobenzene		
Natural Gas					Kg/Kg Chlorobenzene		
Coal	Kg/Kg Chlorob	0			3 Kg/Kg Chlorobenz	0	
Iron ore	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Benzene	Kg/Kg Chlorob	0.693971215			3 Kg/Kg Chlorobenz	0.693971215	
Chlorine	Kg/Kg Chlorob	0.629886283			Kg/Kg Chlorobenz	0.629886283	
Sodium hydroxide (dry bassi	Kg/Kg Chlorob	0.008664743			Kg/Kg Chlorobenz	0.008664743	
Clay	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	

Water

Raw/	Raw/	Raw/	Transformed	Transformed	Transformed

Chlorobenzene

LCl component	Input Units	Input Quan.	Input Std. Dev.	DQI	Units	Quan.	Std. Dev.
COD	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
BOD	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Acid as H+	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Metal ions	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Cl2	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Dissolved Organics	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
suspended solids	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
crude oil	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
miscellaneous dissolved mate	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Phenol	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	

Solid waste

LCl component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not inert)	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0.00128	
Toxic chemicals	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0.000001	
Ash	Kg/Kg Chlorob	0					

Sheet End

1993

8.85E+07

48381000

mono chlorobenzenes
dichlorobenzenesCapacities production
Mlb

	DHfo kcal/mol	DHrx (synthesis) kJoules/kg prod	Refrigeration water flow Heat consumpm ³ /kg prod kJ/kg prod	pump for co material kJ Elec/Kg pkJ Elec/Kg prod	pump for co Elec total pkJ Elec/Kg	Heat total pkJ/kg prod
50 15767000 o	39.995	-13.839 -393.5171 from mono	605.410989 0.1649158 1011.6387	0.0129832 0.0005511		
75 32614000 p	39.995	-13.839 -393.5171 from mono	605.410989 0.1649158 2092.572	0.0129832 0.0005511		
150 8.85E+07 mono	13.882	-13.839 -513.9216 from benzen	790.64868 0.2153751 7415.7123	0.0169556 0.0005511	3605.6934	0.0775256 0.0061033 0.02361 4396.3421
HCl	-39.952		65% efficiency			
Benzene	-12.231		42.8 Btu/ton*min 45.15828 kJ/ton*min			

7 pumping stages per material

	water requir	cooling value of water Btu/lb kJ/kg
	3.25 gal water/ton*min 0.0002724 m ³ /kg	19.99683 Btu/lb 46.509688 kJ/kg

	production factor for plant 40 hr week 52 week year
	150/371 77.50% pump efficiency

	250 ft representative head value 65% heat removal efficiency
	150/371 77.50% pump efficiency

	10% of vaporization heat * recycle
	10% of vaporization heat * recycle

separations

Distill mono from 75% to 100% with 10% heavy, 10% light

minimum energy

10% of vaporization heat * recycle

Heat

Cool

110.6

78.54

80.1 Medium/Eas

0.01 waste

Heat

Cool

145.2

104.16

87.613333 100.43333

Heat

Cool

145.2

106.17

Heat

Cool

136.2

Heat

Cool

180.5

112.56

147.01

147.01

173

Sheet Title:

benzene (for chemical and styrene monomer production)

Sheet Description:

This page calculates the vendor-independent emissions from european refineries producing technical quality benzene

Included are oil extraction and transportation from the well head to the refinery.

References/Citations:

SimaPro3 (entry of Nov 18 94)

Average data for 19 european cracking facilities producing monomer quality ethylene.

taken from:

PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994

report 4, tbi 12 pg 10

Summary Output

Co-product Allocation Calculations						
Co-product		Quantity	Units			
benzene		1.00E+00	Kg			
Total		1	Kg			

LCI components						
		Unallocated	Quantity	Std. Dev.	Allocated	Quantity
		Units			Units	
Air						
COD	Kg/Kg benzene		0.0009			3
BOD	Kg/Kg benzene		0.003			3
Acid as H+	Kg/Kg benzene		0.0068			3
Nitrate	Kg/Kg benzene		0.0006			3
Metal ions	Kg/Kg benzene		0.54			3
Cl2	Kg/Kg benzene		0.000005			3
ammonia	Kg/Kg benzene		0.00015			3
dissolved organi	Kg/Kg benzene		0.0083			3
Crude	Kg/Kg benzene		0.000001			3
dissolved substak	Kg/Kg benzene		0.00054			3
HC's	Kg/Kg benzene		0.00008			
unknown (N)	Kg/Kg benzene		0.000001			
Water						
COD	Kg/Kg benzene		0.0002			3
BOD	Kg/Kg benzene		0.00002			3
Acid as H+	Kg/Kg benzene		0.00004			3
Metal ions	Kg/Kg benzene		0.00036			3

Cl2	Kg/Kg benzene	0.00009	3
Dissolved Organic benzene	Kg/Kg benzene	0.000015	3
suspended solid benzene	Kg/Kg benzene	0.00012	3
crude oil	Kg/Kg benzene	0.0001	3
miscellaneous dis	Kg/Kg benzene	0.00054	3
total HC's	Kg/Kg benzene	0.00008	3
Phenol	Kg/Kg benzene	0.000001	3
Solid Wastes			
Production waste	Kg/Kg benzene	0.00966	3
Resource Consumption			
Natural Gas	Kg/Kg benzene	0.786521739	3
Natural Gas	Kg/Kg benzene	0.159347826	#VALUE!
Crude Oil	Kg/Kg benzene	0.624041192	#VALUE!
Crude Oil	Kg/Kg benzene	0.031605534	#VALUE!
Coal	Kg/Kg benzene	0.000358269	
Coal	Kg/Kg benzene	0.022929203	3
Hydropower	MJ/Kg benzene	0.07	
Fission	MJ/Kg benzene	0.2	
Iron ore	Kg/Kg benzene	0.00015	
limestone	Kg/Kg benzene	0.00011	
Bauxite	Kg/Kg benzene	0.00022	
Rock salt	Kg/Kg benzene	0.0058	
Clay	Kg/Kg benzene	0.00002	
Water	Kg/Kg benzene	2.209	

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors			
Unit from	Unit to	Multiplier	Reference
BTU	J	1055.056	CRC, 66th Edition
Wh	J	3600	CRC, 66th Edition
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed.
gal	L	3.785412	CRC, 66th Edition
kg	lb	2.2046226	CRC, 66th Edition
yr	day	365	
m ³	bbl (petroleum)	6.289811	CRC, 66th Edition

Figure 9-4 @ S.G. = .76 and sulfur = 0.5%

gal CrO	lb CrO	7.2
ton	lb	2000
gal fuel oil	BTU fuel oil	138000
cu. ft NG	BTU NG	1032
lb Coal (dry)	BTU Coal	12000
kg NG	MJ NG	46

Chemical Engineers' Handbook, 6th ed.
SD=11%
SD=13%

Calculations

Ethylene Production

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
benzene (polymer)	1 Kg				3		
benzene (other)							

SimaPro3

Average data for 19 european cracking facilities producing monomer quality benzene.

taken from:

PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994

report 2, tbl 36 pg 21

Energy input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Coal	MJ/Kg benzene	0.64			3 Kg/Kg benzene	0.022929203	
Oil	MJ/Kg benzene	1.41			3 Kg/Kg benzene	0.031605534	
Natural Gas	MJ/Kg benzene	7.33			3 Kg/Kg benzene	0.159347826	
Hydropower	MJ/Kg benzene	0.07			3 MJ/Kg benzene	0.07	
Fission	MJ/Kg benzene	0.2			3 MJ/Kg benzene	0.2	

Probably different mix in US

Material input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil	MJ/Kg benzene	27.84			3 Kg/Kg benzene	0.624041192	
Natural Gas	MJ/Kg benzene	36.18			3 Kg/Kg benzene	0.786521739	
Coal	MJ/Kg benzene	0.01			3 Kg/Kg benzene	0.000358269	
Iron ore	Kg/Kg benzene	0.00015			3 Kg/Kg benzene	0.00015	
limestone	Kg/Kg benzene	0.00011			3 Kg/Kg benzene	0.00011	
Bauxite	Kg/Kg benzene	0.00022			3 Kg/Kg benzene	0.00022	
Rock salt	Kg/Kg benzene	0.0058			3 Kg/Kg benzene	0.0058	
Clay	Kg/Kg benzene	0.00002			3 Kg/Kg benzene	0.00002	
Water	Kg/Kg benzene	2.209			3 Kg/Kg benzene	2.209	

Output
Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/Kg benzene	0.0009			Kg/Kg benzene	0.0009	
SOx	Kg/Kg benzene	0.003			Kg/Kg benzene	0.003	
NOx	Kg/Kg benzene	0.0068			Kg/Kg benzene	0.0068	
CO	Kg/Kg benzene	0.0006			Kg/Kg benzene	0.0006	
CO2	Kg/Kg benzene	0.54			Kg/Kg benzene	0.54	
H2S	Kg/Kg benzene	0.000005			Kg/Kg benzene	0.000005	
HCl	Kg/Kg benzene	0.00015			Kg/Kg benzene	0.00015	
total HC's	Kg/Kg benzene	0.0083			Kg/Kg benzene	0.0083	
Heavy metals	Kg/Kg benzene	0.000001			Kg/Kg benzene	0.000001	

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg benzene	0.0002			Kg/Kg benzene	0.0002	
BOD	Kg/Kg benzene	0.00002			Kg/Kg benzene	0.00002	
Acid as H+	Kg/Kg benzene	0.00004			Kg/Kg benzene	0.00004	
Nitrate	Kg/Kg benzene	0.000001			Kg/Kg benzene	0.000001	
Metal ions	Kg/Kg benzene	0.00036			Kg/Kg benzene	0.00036	
Cl2	Kg/Kg benzene	0.00009			Kg/Kg benzene	0.00009	
ammonia	Kg/Kg benzene	0.00009			Kg/Kg benzene	0.00009	
dissolved organics	Kg/Kg benzene	0.000015			Kg/Kg benzene	0.000015	
suspended particles	Kg/Kg benzene	0.00012			Kg/Kg benzene	0.00012	
Crude	Kg/Kg benzene	0.0001			Kg/Kg benzene	0.0001	
dissolved substances	Kg/Kg benzene	0.00054			Kg/Kg benzene	0.00054	
HC's	Kg/Kg benzene	0.00008			Kg/Kg benzene	0.00008	
unknown (N)	Kg/Kg benzene	0.000001			Kg/Kg benzene	0.000001	

Solid waste

Production waste (not inert)	Kg/Kg benzene	0.00966			Kg/Kg benzene	0.00966	
Toxic chemicals	Kg/Kg ethylene	0.000001			Kg/Kg ethylene	0.000001	

Sheet End

Benzene Coal

Coal type	MoistureSulfur		%dry	Heat value		
	%	%		Btu/lb	Btu/lbdry	
Sub bit C	26	0.3	0.41	8230	11122	
HV bit A	2.9	0.6	0.62	14170	14593	low sulfur coal heating value
Sub bit B	22.2	0.5	0.64	9610	12352	
Brown CGerman	55	0.3	0.67	4830	10733	
Sub bit A	13.9	0.6	0.70	10330	11998	SD= 1296 0.108
Meta Anthracite	9	0.7	0.77	10080	11077	Avg= 11979
LV bit	2.9	0.8	0.82	14400	14830	median
Anthracite	4.3	0.8	0.84	12880	13459	
Lignite	36.8	0.9	1.42	7000	11076	
MV bit	2.4	1.5	1.54	14490	14846	
Semi anthracite	2.1	1.7	1.74	13700	13994	
HV bit B	6.7	2.6	2.79	12390	13280	
HV bit C	15.4	2.9	3.43	10740	12695	

bit=Bituminous

V=Volatility

L=low

M=Medium

H=high

Source: Kirk Othmer vol 4 1949

Benzene NG

Natural gas

	Mwt	heat val	Rio Arrib	Terrell, T	Stanton, San	Jua	Olds Fie	Cliffside, Texas		
mol%		MJ/M^3								
Methane	16.04	37.57	96.91	45.64	67.56	77.28	52.34	65.8		
ethane	30.07	65.83	1.33	0.21	6.23	11.18	0.41	3.8		
propane	44.1	93.6	0.19		3.18	5.83	0.14	1.7		
butane	58.12	121	0.05		1.42	2.34	0.16	0.8		
pentane	72.15	148.8	0.02		0.04	1.18	0.41	0.5		
CO2	44.01	0	0.82	53.93	0.07	0.8	8.22			
H2S	34.08	23.7		0.01			35.79			
N2	28.01	0	0.68	0.21	21.14	1.39	2.53	25.6	avg	SD (rel)
Mol wt:			16.63	31.18	20.92	21.28	25.49	20.45	19.61	10.79%
heating MJ/M^3			37.6	17.3	34.9	46.8	30	30.7	39.77	12.81%
MJ/KG			50.66	12.43	37.37	49.25	26.36	33.63	45.76	13.03%

0.0224M^3/mol too high too high too low
 CO2 Sulfur heating
 content for content value(?)
 use

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
 source Perry 6 (1964)
 averaged from table 9-14

Btu/scf 1050

Synopsis of table 9-14

	Mwt	heat val	Baltimor	Columbu	Houston	Burming	Washing	Phoenix		
mol%		MJ/M^3	Md	Ohio	Tx	Al	DC	Az		
Methane	16.04	37.57	94.4	93.14	92.5	93.14	95.15	87.37		
ethane	30.07	65.83	3.4	3.58	4.8	2.5	2.84	8.11		
propane	44.1	93.6	0.6	0.66	2	0.67	0.63	2.26		
butane	58.12	121	0.5	0.22	0.3	0.32	0.24	0.13		
pentane	72.15	148.8	0	0.09	0	0.12	0.05	0		
CO2	44.01	0	0.6	0.85	0.27	1.06	0.62	0.61		
H2S	34.08	23.7		0.01						
N2	28.01	0	0.5	0.21	21.14	2.14	0.42	1.37	avg	SD (rel)
Mol wt:			17.13	16.94	23.38	17.33	16.96	18.18	18.32	15.84%
heating MJ/M^3			39.2	38.34	38.46	38.2	38.87	39.95	38.84	1.10%
MJ/KG			51.27	50.71	36.84	49.37	51.32	49.22	48.12	13.30%

0.0224M^3/mol

Sheet Title: Chlorine

Sheet Description: This page calculates the vendor-independent emissions from european manufacture of chlorine gas.

References/Citations: SimaPro3 (entry of Nov 18 94)
Average european data for NaOH/Cl₂ producers.
taken from:
PWWI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 6, tbl 15 pg 13 and report 5 (allocation)

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units
chlorine	1.00E+00	Kg
NaOH		data after allocation
Total	1	Kg

LCI components	Unallocated		Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
	Units	Units						
Air								
Water								
COD	Kg/Kg chlorine		0.00001					3
BOD	Kg/Kg chlorine		0.000003					3
Acid as H+	Kg/Kg chlorine		0.00034					3
Metal ions	Kg/Kg chlorine		0.00009					3
Cl2	Kg/Kg chlorine		0.042					3
suspended solid	Kg/Kg chlorine		0.002					3
miscellaneous dis	Kg/Kg chlorine		0.00005					3
sodium	Kg/Kg chlorine		0.0028					3
Solid Wastes								
Production waste	Kg/Kg chlorine		0.099					3
Resource Consumption								
fuel	Natural Gas	Kg/Kg chlorine	0.088043478			3375000		3
fuel	Crude Oil	Kg/Kg chlorine	0.079350065			14.11883921		3

fuel	Coal	Kg/Kg chlorine	0.242547977	43.15681238	3
	Hydropower	MJ/Kg chlorine	0.72		
	Fission	MJ/Kg chlorine	6.14		
	Iron ore	Kg/Kg chlorine	0.00065		
	limestone	Kg/Kg chlorine	0.0186		
	Rock salt	Kg/Kg chlorine	1.21		
	Water	Kg/Kg chlorine	0.9		
	sand	Kg/Kg chlorine	0.00002		

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors		Unit to	Multiplier	Reference	
BTU	J	J	1055.056	CRC, 66th Edition	
Wh	J	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed.	
gal	L	L	3.785412	CRC, 66th Edition	
kg	lb	lb	2.2046226	CRC, 66th Edition	
yr	day	day	365		
m^3	bbl (petroleum)	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	lb CrO	7.2		
ton	lb	lb	2000		
gal fuel oil	BTU fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry)	BTU Coal	BTU Coal	12000	calculation page B SD=11%	
kg NG	MJ NG	MJ NG	46	Calculated page C SD=13%	

Calculations

Ethylene Production					
LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units
chlorine (polymer)	1 Kg			3	
chlorine (other)					

SimaPro3

Average data for 19 european cracking facilities producing monomer quality chlorine.
taken from:

0

Energy input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Coal	MJ/Kg chlorine	6.77			3 Kg/Kg chlorine	0.242547977	
Oil	MJ/Kg chlorine	3.54			3 Kg/Kg chlorine	0.079350065	
Natural Gas	MJ/Kg chlorine	4.05			3 Kg/Kg chlorine	0.088043478	
Hydropower	MJ/Kg chlorine	0.72			3 MJ/Kg chlorine	0.72	
Fission	MJ/Kg chlorine	6.14			3 MJ/Kg chlorine	6.14	

Probably different mix in US

Material input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil	MJ/Kg chlorine	0			3 Kg/Kg chlorine	0	
Natural Gas	MJ/Kg chlorine	0			3 Kg/Kg chlorine	0	
Coal	MJ/Kg chlorine	0			3 Kg/Kg chlorine	0	
Iron ore	Kg/Kg chlorine	0.00065			3 Kg/Kg chlorine	0.00065	
limestone	Kg/Kg chlorine	0.0186			3 Kg/Kg chlorine	0.0186	
Bauxite	Kg/Kg chlorine	0			3 Kg/Kg chlorine	0	
Rock salt	Kg/Kg chlorine	1.21			3 Kg/Kg chlorine	1.21	
Clay	Kg/Kg chlorine	0			3 Kg/Kg chlorine	0	
Water	Kg/Kg chlorine	0.9			3 Kg/Kg chlorine	0.9	
sand	Kg/Kg chlorine	0.00002			3 Kg/Kg chlorine	0.00002	

Output

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/Kg chlorine	0.0035			Kg/Kg chlorine	0.0035	
SOx	Kg/Kg chlorine	0.012			Kg/Kg chlorine	0.012	
NOx	Kg/Kg chlorine	0.007			Kg/Kg chlorine	0.007	
CO	Kg/Kg chlorine	0.0008			Kg/Kg chlorine	0.0008	
CO2	Kg/Kg chlorine	1.21			Kg/Kg chlorine	1.21	
H2S	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
HCl	Kg/Kg chlorine	0.00018			Kg/Kg chlorine	0.00018	
total HC's	Kg/Kg chlorine	0.006			Kg/Kg chlorine	0.006	
Heavy metals	Kg/Kg chlorine	0.000002			Kg/Kg chlorine	0.000002	

Water

Raw/	Raw/	Raw/	Raw/	Transformed	Transformed

LCI component	Input Units	Input Quan.	Input Std. Dev.	DQI	Units	Quan.	Std. Dev.
COD	Kg/Kg chlorine	0.00001			Kg/Kg chlorine	0.00001	
BOD	Kg/Kg chlorine	0.000003			Kg/Kg chlorine	0.000003	
Acid as H+	Kg/Kg chlorine	0.00034			Kg/Kg chlorine	0.00034	
Nitrate	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
Metal ions	Kg/Kg chlorine	0.00009			Kg/Kg chlorine	0.00009	
Cl2	Kg/Kg chlorine	0.042			Kg/Kg chlorine	0.042	
ammonia	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
dissolved organics	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
suspended particles	Kg/Kg chlorine	0.002			Kg/Kg chlorine	0.002	
Crude	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
dissolved substances	Kg/Kg chlorine	0.00005			Kg/Kg chlorine	0.00005	
HC's	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
sodium	Kg/Kg chlorine	0.0028			Kg/Kg chlorine	0.0028	
Solid waste							
Production waste (not inert)	Kg/Kg chlorine	0.099			Kg/Kg chlorine	0.099	
Toxic chemicals	Kg/Kg chlorine	0.00002			Kg/Kg chlorine	0.000001	

CrO from Alaska	1000 bbl/day	1798					ton/yr	99228024	
Total							ton/yr	99228024	
Water Shipping - Lower 48	mi	0					ton-mi/yr	0	
Water Shipping - Alaska	mi	2439.6					ton-mi/yr	2.42077E+11	
Crude Oil Transport									
Association of Oil Pipe Lines Data for 1990									
LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.		
Pipelines	mi	0							
Water	mi	2439.6							
Highway/Motor Carrier	mi	1000							
Rail	mi	697							
LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.		
Pipelines	BTU/ton-mi	0							
Water	BTU/ton-mi	361			gal fuel/bbl CrO	0.964936049			
Highway/Motor Carrier	BTU/ton-mi	434			gal fuel/bbl CrO	0.553762025			
Rail	BTU/ton-mi	434			gal fuel/bbl CrO	0.385972132			
Water Transport Emissions									
LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.		
SOx	lb/1000 gal fuel	27			kg/bbl CrO	0.011817566			
CO	lb/1000 gal fuel	100			kg/bbl CrO	0.043768763			
HC	lb/1000 gal fuel	50			kg/bbl CrO	0.021884382			
NOx	lb/1000 gal fuel	280			kg/bbl CrO	0.122552537			
HC - transfer	lb/1000 gal hauled	0.97			kg/bbl CrO	0.018479353			
Highway Transport Emissions									

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
HC	lb/1000 gal fuel	5.4572			kg/bbl CrO	0.001370752	
CO	lb/1000 gal fuel	15.3321			kg/bbl CrO	0.003851151	
NOx	lb/1000 gal fuel	18.6622			kg/bbl CrO	0.004687613	
HC - transfer	lb/1000 gal hauled	3.25			kg/bbl CrO	0.061915359	

Railroad Transport Emissions

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	lb/1000 gal fuel	25			kg/bbl CrO	0.00437685	
SOx	lb/1000 gal fuel	57			kg/bbl CrO	0.009979219	
CO	lb/1000 gal fuel	130			kg/bbl CrO	0.022759622	
HC	lb/1000 gal fuel	94			kg/bbl CrO	0.016456957	
NOx	lb/1000 gal fuel	370			kg/bbl CrO	0.064777386	
Aldehydes	lb/1000 gal fuel	5.5			kg/bbl CrO	0.000962907	
Organic Acids	lb/1000 gal fuel	7			kg/bbl CrO	0.001225518	
HC - transfer	lb/1000 gal hauled	3.25			kg/bbl CrO	0.061915359	

Sheet End

Sheet Title: Isopropanol (from Propene and Isobutylene. Isopropanol is used in production of TNAZ)

Sheet Description: Emissions are from TRI database.
Engineering calculation of the Energy requirements and precursor requirements .
This page calculates the vendor emissions from a plant producing Isopropanol.
Not included are raw material production or extraction or water use.

References/Citations:

Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11, 1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11, 1994

Mwt	Co-product	Quantity	Units	Quantity	Units	BP deg C	Sp G	Vapor density relative to air
60.0956	Isopropanol	1.00E+00	kg	1.00E+00	kg	8.2	1.392	3.4
Total		1.00E+00	Kg	1.00E+00	Kg			

Notes:

LCI components		Unallocated		Allocated		Quantity		Std. Dev.		DQI	
		Units		Units							
Air											
Isopropanol Propene	Kg/kg Isopropanol	0.000651899		Kg/kg Isopropanol		0.000651899				5	
	Kg/kg Isopropanol	2.56305E-05		Kg/kg Isopropanol		2.56305E-05				5	
Water											
Na2SO4	Kg/kg Isopropanol	0.016909798		Kg/kg Isopropanol		0.016909798				5	
Solid Wastes											
Resource Consumption											
Heat Energy (tos MJ/Kg Isopropanol		5.205045039		MJ/Kg Isopropanol		5.205045039				3	

Electric Power	MJ/Kg Isopropa	3.71126E-05	MJ/Kg Isopropa	3.71126E-05	3
Propene	Kg/kg Isopropa	0.989010989	Kg/kg Isopropa	0.989010989	5
sulfuric acid	Kg/kg Isopropa	0.011675824	Kg/kg Isopropa	0.011675824	4
NaOH	Kg/kg Isopropa	0.009523461	Kg/kg Isopropa	0.009523461	3

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference
Wh	J	1055.056	CRC, 66th Edition
BTU	J	3600	CRC, 66th Edition
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed.
gal	L	3.785412	CRC, 66th Edition
kg	lb	2.2046226	CRC, 66th Edition
yr	day	365	
p.s.i.	feet water	2.03666	CRC, 66th Edition
m ³	bbl (petroleum)	6.289811	CRC, 66th Edition
gal CrO	lb CrO	7.2	
ton	lb	2000	
gal fuel oil	BTU fuel oil	138000	
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.
lb Coal (dry/BTU Coal		12000	calculation page B
kg NG.	MJ NG	46	calculation page C
d Isopropan	0.74 rel to Water	molar	
Mw Chlorin	70.9	dry air composition	
Mw ClBz	112.56	N2	0.78084
Mw Cl2Bz	147.01	O2	0.20946
Mw HCl	36.4609	CO2	0.00033
Mw NaOH	39.9971	Ar	0.00934
		total	0.99997
			28.96409
			1
			kg air per kg
			mass composition component
			0.75521
			1.324134
			0.231406
			4.321406
			0.000501
			1994.319
			0.012882
			77.62792

Ideal gas density at 15 C (60 F)
 0.042296 mol/liter 42.29634021 mol/m³ air (dry)
 1.225075005 kg/m³

Calculations

Isopropanol Production		1983
Source:	US ITC 2810 11.94 Synthetic Organic Che Kg	576945000
	US Production and Sales, 1993	
Isopropanol production capacity		
Source:	Chem & Eng. News	1800
	Chemical Profile	
	Aug 9 '93	
	Utilization ratio:	0.70651418
	Capacity	Calculated production:
	Mlb	Mlb
Exxon	Baton Rouge, LA 70821	650 459.2342169

Shell Oil Co. Deer Park, TX 77536 600 423.9085079
 Union Carbide Texas City, TX 77590 550 388.5827989

Source: Emissions:
 TRI database, 1993 data

The following reported emissions were ascribed to isopropanol production Isopropanol Propene sulfuric acid Isopropyl ether

Exxon	Raw/	Raw/	Raw/	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	Input Units	Input Std. Dev.	Input Std. Dev.				
Fossil fuel (general)	MJ/kg Isopropanol	5.20504504			MJ/kg Isopropanol	5.205045039	
Coal	MJ/kg Isopropanol	0			Kg/kg Isopropanol	0	
Oil	MJ/kg Isopropanol	0			Kg/kg Isopropanol	0	
Natural Gas	MJ/kg Isopropanol	0			Kg/kg Isopropanol	0	
Hydropower	MJ/kg Isopropanol	0			Kg/kg Isopropanol	0	
Fission	MJ/kg Isopropanol	0					
Electricity (generic)	MJ/kg Isopropanol	3.71126E-05			MJ/kg Isopropanol	3.71126E-05	

Isopropanol evaporation	from acid	D H v MJ/Kg	Kg/kg Isopropanol MJ/Kg Propanol
water evaporation	Acid reconstitution	60.0956 10063.5	0.700645039 1 0.700645039
	CRC 66	2.2522	2 4.5044
		Perry's 6	5.205045039 heat load

Heating load is disregarded because of the overwhelming energy requirements of evaporation and the probable recovery of that energy for other heating purposes.

Cooling water	25 deg C temp rise	Condensation
0.1046 MJ/kg product	heat removal	
5.205045 MJ/kg product	heat load	
49.76142 Kg/Kg product		

0.7 efficiency

7.87E-05 kJ/ElecKg Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

distillation bottlo storage	kg flow/kg propanepresentative	Sp grav	Sp Visc	1.54392E-07	25C
	1 Isopropanol	0.7855	2.496666667		
storage to reactor	0.25 mineral oil/whit	0.7628	2.18 MJ/kg Isopropanol	3.27284E-08	83 C
water dilution 2 to acid bottle	12 sulfuric acid +w	2.02196	1.966466667	3.75628E-06	25 C
acid+propene ato dilution	5 sulfuric acid +w	1.899	21.7403 MJ/kg Isopropanol	1.62509E-05	25 C
clean acid to absorber	4 sulfuric acid +w	1.899	21.7403 MJ/kg Isopropanol	1.30008E-05	25 C
water	49.76142485			3.91752E-06	
		CRC 66	1	3.71126E-05	
				total pumping energy per kg prod	

Absorber materials at 4*weight of product stream

Co-Products:
 source: See from above

Resources: Faith, Keyes and Clark's Industrial chemicals

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil	Kg/kg Isopropa	0	0		Kg/kg Isopropanol	0	
Natural Gas	Kg/kg Isopropa	0	0		Kg/kg Isopropanol	0	
Coal	Kg/kg Isopropa	0	0		Kg/kg Isopropanol	0	
42.0804 Propene	Kg/31kg Isopro	0.9	0.010625		5 Kg/kg Isopropanol	0.989010989	
98.0734 sulfuric acid	Kg/31kg Isopro	0.010625	0		4 Kg/kg Isopropanol	0.011675824	
"Mineral oil"	Kg/kg Isopropa	0	0		Kg/kg Isopropanol	0	
39.9971 NaOH	Kg/31kg Isopro	0.00866635	0		3 Kg/kg Isopropanol	0.009523461	
Water	Kg/kg Isopropa	0	0		Kg/kg Isopropanol	0	

Eng Estimate based on H2SO4 make up for treatment

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	lb/Exxon +Shel	0	0		Kg/kg Isopropanol	0	
SOx	lb/Exxon +Shel	0	0		Kg/kg Isopropanol	0	
NOx	lb/Exxon +Shel	0	0		Kg/kg Isopropanol	0	
Cl2	lb/Exxon +Shel	0	0		Kg/kg Isopropanol	0	
Isopropanol	lb/Exxon +Shel	0.00E+00	0		5 Kg/kg Isopropanol	0	
Propene	lb/Exxon +Shel	8.29E+05	0		5 Kg/kg Isopropanol	0.000651899	
sulfuric acid	lb/Exxon +Shel	3.26E+04	0		5 Kg/kg Isopropanol	2.56305E-05	
Isopropyl ether	lb/Exxon +Shel	0.00E+00	0		5 Kg/kg Isopropanol	0	
HC total	lb/Exxon +Shel	0.00E+00	0		Kg/kg Isopropanol	0	
Heavy meta(Cd+Ni+Cr)	lb/Exxon +Shel	0	0		Kg/kg Isopropanol	0	

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	lb/Exxon +Shel	0	0		Kg/kg Isopropanol	0	
BOD	lb/Exxon +Shel	0	0		Kg/kg Isopropanol	0	
Acid, H+ (Phosphoric)	lb/Exxon +Shel	0	0		Kg/kg Isopropanol	0	
Metal ions	lb/Exxon +Shel	0	0		Kg/kg Isopropanol	0	
Na2SO4 in water	lb/Exxon +Shel	0	0		3 Kg/kg Isopropanol	0.016909798	
Isopropanol	lb/Exxon +Shel	0.00E+00	0		Kg/kg Isopropanol	0	
Propene	lb/Exxon +Shel	0.00E+00	0		Kg/kg Isopropanol	0	
sulfuric acid	lb/Exxon +Shel	0.00E+00	0		Kg/kg Isopropanol	0	
Isopropyl ether	lb/Exxon +Shel	0.00E+00	0		Kg/kg Isopropanol	0	
Heavy metals (Cadmium, Nickel)	lb/Exxon +Shel	0	0		Kg/kg Isopropanol	0	

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not inert)	lb/Exxon +Glob	0	0		Kg/kg Isopropanol	0	
Heavy metals (Cadmium, Nickel)	lb/Exxon +Glob	0	0		Kg/kg Isopropanol	0	

Offsite Transfer

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.

Sheet Title:

Propylene (for polypropylene production)

Sheet Description:

This page calculates the vendor-independent emissions from european refineries producing monomer quality propylene

Included are oil extraction and transportation from the well head to the refinery.

References/Citations:

SimaPro3 (entry of Nov 18 94)

Average data for 19 european cracking facilities producing monomer quality ethylene.

taken from:

PVMI/APME: Ecoprofiles of the European plastics industry, 1992-1994

report 2, tbi 36 pg 21

Summary Output

Co-product Allocation Calculations								
Co-product		Quantity	Units					
Propylene		1.00E+00	Kg					
Total		1	Kg					

LCI components	Unallocated		Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
	Units	Units						
Air								
TSP		Kg/Kg propylene	0.0008					3
SOx		Kg/Kg propylene	0.004					3
NOx		Kg/Kg propylene	0.006					3
CO		Kg/Kg propylene	0.0004					3
CO2		Kg/Kg propylene	0.528					3
H2S		Kg/Kg propylene	0.00001					3
HCl		Kg/Kg propylene	0.00001					3
total HC's		Kg/Kg propylene	0.008					3
other organic		Kg/Kg propylene	0.000001					3
Heavy metals		Kg/Kg propylene	0.000001					3
Water								
COD		Kg/Kg propylene	0.0002					3
BOD		Kg/Kg propylene	0.00003					3
Acid as H+		Kg/Kg propylene	0.00004					3
Metal ions		Kg/Kg propylene	0.0002					3
Cl2		Kg/Kg propylene	0.00005					3

Dissolved Organ	Kg/Kg propylene	0.00002	3
suspended solid	Kg/Kg propylene	0.0002	3
crude oil	Kg/Kg propylene	0.0001	3
miscellaneous dis	Kg/Kg propylene	0.0004	3
Phenol	Kg/Kg propylene	0.00007	3
Solid Wastes			
Production waste	Kg/Kg propylene	0.009	3
Resource Consumption			
Natural Gas	Kg/Kg propylene	0.514130435	3
Coal	Kg/Kg propylene	0.000358269	19708333.33
Coal	Kg/Kg propylene	0.020063053	3
Hydropower	MJ/Kg propylene	0.12	3.569899724
Fission	MJ/Kg propylene	0.23	
Iron ore	Kg/Kg propylene	0.0002	
limestone	Kg/Kg propylene	0.0001	
Bauxite	Kg/Kg propylene	0.0003	
Rock salt	Kg/Kg propylene	0.006	
Clay	Kg/Kg propylene	0.00002	
Water	Kg/Kg propylene	1.6	

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors		Unit to	Multiplier	Reference
BTU	J		1055.056	CRC, 66th Edition
Wh	J		3600	CRC, 66th Edition
bbl CrO	BTU CrO		5800000	Chemical Engineers' Handbook, 6th ed.
bbl	gal		42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel		118500	Chemical Engineers' Handbook, 6th ed.
gal	L		3.785412	CRC, 66th Edition
kg	lb		2.2046226	CRC, 66th Edition
yr	day		365	
m ³	bbl (petroleum)		6.289811	CRC, 66th Edition
gal CrO	lb CrO		7.2	
ton	lb		2000	
gal fuel oil	BTU fuel oil		138000	
cu. ft NG	BTU NG		1032	Chemical Engineers' Handbook, 6th ed.
lb Coal (dry)	BTU Coal		12000	calculation page B SD=11%

Calculations

Ethylene Production

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Propylene (polymer)	1 Kg				3		
Propylene (other)							

SimaPro3

Average data for 19 european cracking facilities producing monomer quality propylene.

taken from:

PwMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

0

Energy input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Coal	MJ/Kg propylene	0.56			3 Kg/Kg propylene	0.020063053	
Oil	MJ/Kg propylene	1.86			3 Kg/Kg propylene	0.041692407	
Natural Gas	MJ/Kg propylene	6.68			3 Kg/Kg propylene	0.145217391	
Hydropower	MJ/Kg propylene	0.12			3 MJ/Kg propylene	0.12	
Fission	MJ/Kg propylene	0.23			3 MJ/Kg propylene	0.23	

Probably different mix in US

Material input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil	MJ/Kg propylene	36.38			3 Kg/Kg propylene	0.81546762	
Natural Gas	MJ/Kg propylene	23.65			3 Kg/Kg propylene	0.514130435	
Coal	MJ/Kg propylene	0.01			3 Kg/Kg propylene	0.000358269	
Iron ore	Kg/Kg propylene	0.0002			3 Kg/Kg propylene	0.0002	
limestone	Kg/Kg propylene	0.0001			3 Kg/Kg propylene	0.0001	
Bauxite	Kg/Kg propylene	0.0003			3 Kg/Kg propylene	0.0003	
Rock salt	Kg/Kg propylene	0.006			3 Kg/Kg propylene	0.006	
Clay	Kg/Kg propylene	0.00002			3 Kg/Kg propylene	0.00002	
Water	Kg/Kg propylene	1.6			3 Kg/Kg propylene	1.6	

Output

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/Kg propylene	0.0008			Kg/Kg propylene	0.0008	
SOx	Kg/Kg propylene	0.004			Kg/Kg propylene	0.004	
NOx	Kg/Kg propylene	0.006			Kg/Kg propylene	0.006	

CO	Kg/Kg propylene	0.0004	Kg/Kg propylene	0.0004
CO2	Kg/Kg propylene	0.528	Kg/Kg propylene	0.528
H2S	Kg/Kg propylene	0.00001	Kg/Kg propylene	0.00001
HCl	Kg/Kg propylene	0.00001	Kg/Kg propylene	0.00001
total HC's	Kg/Kg propylene	0.008	Kg/Kg propylene	0.008
other organic	Kg/Kg propylene	0.000001	Kg/Kg propylene	0.000001
Heavy metals	Kg/Kg propylene	0.000001	Kg/Kg propylene	0.000001

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg propylene	0.0002			Kg/Kg propylene	0.0002	
BOD	Kg/Kg propylene	0.00003			Kg/Kg propylene	0.00003	
Acid as H+	Kg/Kg propylene	0.00004			Kg/Kg propylene	0.00004	
Metal ions	Kg/Kg propylene	0.0002			Kg/Kg propylene	0.0002	
Cl2	Kg/Kg propylene	0.00005			Kg/Kg propylene	0.00005	
Dissolved Organics	Kg/Kg propylene	0.00002			Kg/Kg propylene	0.00002	
suspended solids	Kg/Kg propylene	0.0002			Kg/Kg propylene	0.0002	
crude oil	Kg/Kg propylene	0.0001			Kg/Kg propylene	0.0001	
miscellaneous dissolved mater	Kg/Kg propylene	0.0004			Kg/Kg propylene	0.0004	
Phenol	Kg/Kg propylene	0.00007			Kg/Kg propylene	0.00007	

Solid waste

Production waste (not inert)	Kg/Kg propylene	0.009	Kg/Kg propylene	0.009

Prop. Coal

Coal type	Moisture %	Sulfur %	%dry	Heat value Btu/lb	Btu/lbdry	low sulfur coal heating value
Sub bit C	26	0.3	0.41	8230	11121.622	
HV bit A	2.9	0.6	0.62	14170	14593.203	
Sub bit B	22.2	0.5	0.64	9610	12352.185	
Brown Coal German - Rh	55	0.3	0.67	4830	10733.333	
Sub bit A	13.9	0.6	0.70	10330	11997.677	SD= 1295.7751 0.1081691
Meta Anthracite	9	0.7	0.77	10080	11076.923	Avg= 11979.157
LV bit	2.9	0.8	0.82	14400	14830.072	median
Anthracite	4.3	0.8	0.84	12880	13458.725	
Lignite	36.8	0.9	1.42	7000	11075.949	
MV bit	2.4	1.5	1.54	14490	14846.311	
Semi anthracite	2.1	1.7	1.74	13700	13993.871	
HV bit B	6.7	2.6	2.79	12390	13279.743	
HV bit C	15.4	2.9	3.43	10740	12695.035	

bit=Bituminous

V=Volatility

L=low

M=Medium

H=high

Source: Kirk Othmer vol 4 1949

Rio Arriba, N Terrell, Tex Stanton, Kan San Juan, NM Olds Field, A Cliffside, Texas

 $0.0224 \text{ M}^3/\text{mol}$

MJ/m³

Heating values for processed city natural gas:
source Perry 6 (1964)
averaged from table 9-14

Page 1

Prop. NG

ethane	30.07	65.83	3.4	3.58	4.8	2.5	2.84	8.11			
propane	44.097	93.6	0.6	0.66	2	0.67	0.63	2.26			
butane	58.123	120.98	0.5	0.22	0.3	0.32	0.24	0.13			
pentane+	72.15	148.84	0	0.09	0	0.12	0.05	0			
CO2	44.01	0	0.6	0.85	0.27	1.06	0.62	0.61			
H2S	34.076	23.7		0.01							
N2	28.013	0	0.5	0.21	21.14	2.14	0.42	1.37			
Mol wt:			17.126294	16.939122	23.380219	17.328208	16.9628	18.179837	avg	SD (rel)	
heating value	MJ/M^3		39.2023	38.3444	38.4563	38.1952	38.8666	39.9483	18.319413	15.84%	
	MJ/KG		51.273879	50.705967	36.844014	49.374551	51.324771	49.221668	38.835517	1.10%	
									48.124142	13.30%	

0.0224M^3/mol

Phosphorous trichloride production from Phosphorous and chlorine.

	Mwt	DHfo	Cpo
	kg/mol	kcal/mol	Cal/deg mdMJ/Kg deg
P4	123.8952	14.08	0.475488
PCl3	137.3328	-76.4	-2.327613
Cl2	70.906	0	0
water	18.0153		17.995
			4.17929

reaction	79.92	2.434854

yield 0.95 relative to reactants
reflux ratio 0.5

Module Material (Kg/Kg phosphorous trichloride) and Energy in MJ/Kg phosphorous trichloride

Module	Phosphorous	Chlorine	Cooling water	PCl3	Fuel ?	Electricity	Energy loss	Reaction
Reactor	0.308631	0.855984		1.1119838	-2.223968		0.0526316	
	0	0		37.809375	-87.2524		2.4348537	-47.00817
Reflux cooler	25	25		90	100		0	
				2.2239675	-2.223968		11.633654	
				87.252403	-75.61875			
Condenser				100	90			
				1.1119838	-1.111984		0	
				49.443028	-37.80937		11.633654	
Still	-0.071223	-0.040761		100	90			
	-1.93019	-0.974596		1.1119838	-1		-1.11E-16	
	75	75		37.809375	-26.15518		8.7494095	
				90	75			
	0.237409	0.815223	0	-1	-6.559919	0	0	0.0526316

-1.93019 -0.974596 0 0 -14.52153 0 0 2.4348537

Cooling
water

25 deg C temp rise

104.482135 heat removal MJ/kg water

2.43485373 MJ/kg product

0.02330402 Kg/Kg product

c water

7.8726E-05 kJ Elec/Kg Based on viscosity and density of water for a 250 ft static head per pumping stage
in 40hr week & 52 week year daytime operation. multiply by specific gravity of material
and relative viscosity to that of water.

	representati	Sp grav	Sp visc	kgflow/kg prod	
storage to reactor	P4	1.745	2	0.237409	1.9E-08 viscosity is a guess
reflux to reactor	PC13	1.575	2	1.111984	8.8E-08 viscosity is a guess
reflux to condenser	PC13	1.575	2	1.111984	8.8E-08
condenser to still	PC13	1.575	2	1.111984	8.8E-08
recycle to reactor	P4	1.745	2	0.071223	5.6E-09
cooling water		1	1	0.023304	1.8E-09
					2.9E-07 total pumping energy per kg prod

Acetic Anhydride synthesis
Source: all process data

Pg 8

Technical report HDC-125-95

By Laurie J. Brown

Holston Defense Corporation

Subsidiary of Eastman Chemical Co.

Kingsport, TN 37660

New heat source from NG changes coal tar, cinder and Flue gas data.

Final calculation based on producer gas required to consume the air supplied to the process.

The heat value for the producer gas is matched with standard NG, from which air requirements are taken.

Physical data are taken from:

Perry's Chemical Engineer's Handbook, Ed 6

McGraw-Hill, 1984

Kirk-Othmer Encyclopaedia of chemical technology, Ed 2, Ed 4

Wiley Interscience, 1966, 1994

Entires: Gas, Manufactured; Gas, Natural; Coal; Coal tar

Product	Conc.	Raw data in lb	kg per kg AcAnhd solution	kg per kg AcAnhd dry base
AcAnhd (Water)	0.975	2.03	1	1
Total	0.025	2.03	1	0.025641
				1.025641
Output				
scrub				
to IWTF	0.005	0.08455	0.0416502	0.0427182
AcOH	as pure	0.0841273	0.041442	0.0425046
AcOH	as pure	0.0004228	0.0002083	0.0002136
mill washout to IWTF				
W	0.99	0.2146	0.1057143	0.1084249
AcOH	0.01	0.212454	0.1046571	0.1073407
		0.002146	0.0010571	0.0010842
Condensate to IWTF				
AcOH/W	trace	0.06039	0.0297488	0.0305116
Water		0.06039	0.0297488	0.0305116
condensate to steam plant A		5.987	2.9492611	3.0248832
cinders to block plant		0.2186	0.1076847	0.1104459
		0	0	0
				Replaced system
Producer gas manufacture Coal tar to steam plant A				
Coal tar		0.06779	0.0333941	0.0342503
		0	0	0
				NG system
Evaporator sludge from ketene gas manufacture				
to Bldg 2	0.9	0.04026	0.0198325	0.020341
AcOH	0.9	0.036234	0.0178493	0.0183069
W	0.1	0.004026	0.0019833	0.0020341
Scrubber underflow to Bldg 2		0.1208	0.0595074	0.0610332

Refining residue to Bldg 2	AcOH	0.12	0.014496	0.0071409	0.007324	
	W	0.88	0.106304	0.0523665	0.0537092	
Ball mill sludge to Steam Plant B	AcOH	pure	0.3759	0.1851724	0.1899204	
			0.004828	0.0023783	0.0024393	
Inputs	Materials					
	AcOH	0.997	2.884	1.4206897	1.4571176	
	NH3		0.0005629	0.0002773	0.0002844	
	Eth3PO4		0.00856	0.0042167	0.0043249	
	Heat source changed	Air	0.5865	0.2889163	0.2963244	
	Coal		0.6795	0.3347291	0.3433119	
	Replacement System	Air	0.4979873	0.2453139	0.251604	
	Natural Gas		0.0300438	0.0147999	0.0151794	
	EthGlycol		5.306E-05	2.614E-05	2.681E-05	
	Freon		5.383E-06	2.652E-06	2.72E-06	
	Filtered Water		13.14	6.4729064	6.6388784	
	Steam		15.03	7.4039409	7.5937855	
	River Water		1590	783.25123	803.3346	
	Energy					Energy
	Electricity	kWhr	0.1122	0.0552709	0.0566881	
Waste	Water/condensate return to river (Non-contact)					
			1603	789.65517	809.90274	
Air Emission	Steam Condensate to river (Non-contact)					
			8981	4424.1379	4537.5774	
	AcOH		0.0618	0.0304433	0.0312239	
	Flue Gas		0.9797	0.4826108	0.4949855	
	Flue gas		0.5280311	0.2601138	0.2667834	
	Freon		5.383E-06	2.652E-06	2.72E-06	
	Coal tar					
		lb per	0.6795	0.3347291	0.3433119	
		lb RDX base/kgAcAnmix	0.06779	0.0333941	0.0342503	
				0.099764533	10% tar	
This calculation method came up with inconsistent results	Producer gas					
	Heating value	Btu	0.4275059	0.192794	0.1331015	70% gas
	air required		4109.6485	2024.4574	2076.3666	
	NG replacement	nescf	0.675477	0.3327473	0.3412793	
			3.9155492	1.928842	1.9782994	to equal heating values
			0.1904544	0.0938199	0.0962255	
	Air required		3.1568477	1.5550974	1.5949717	
	Air		0.5865	0.2889163	0.2963244	
	Producer gas		0.2554196	0.1258225	0.1290487	calculated according to air supply
	Heating value	btu	648.28993	319.35464	327.54323	calc according to heat of gas combustion
Final calculation method	NG replacement nescf					
			0.6226572	0.3067277	0.3145925	heat value to equal heating values

0.0300438 0.0147999 0.0151794
 0.4979873 0.2453139 0.251604
 1.0140059 0.4817102 0.4294258
 0.2186 0.1076847 0.1104459
 0.9797 0.4826108 0.4949855
 1.1983 0.5902956 0.6054314
 -15.38% is missing output, perhaps to scrubbing

Air required
 Cinder
 Flue gas
 Mass
 balance error

Heating values for processed city natural gas:
 source Perry 6 (1964)
 averaged from table 9-14

Btu/scf 1049.571429
 MJ/M³ 39.14901429
 MJ/Kg 50.18997432

Manufactured gas

Data from KO 2 (1964) for "modern mechanical method"

	Moisture		Heating value/Btu/lb		Gas		gas lb/lb coal		Gross heat value Btu/scf		Btu/ton coal		Tar data		lb/lb coal		energy value	
	wet	dry	wet base	dry base	wet base	dry base	wet base	dry base	wet base	dry base	wet base	dry base	wet base	dry base	wet	dry	btu in tar/lb coal	
Anthracite	0.051	10800	11380.4	123900	130558.48	120900	124127.31	138	145.41623	17098200	8549.1	9.5	10.010537	0.0475688	0.0050072	810	17027.962	
Belgian Coal	0.026	11980	12293.795	120900	124127.31	150	154.00411	18135000	9067.5	1	1.026694			0.0050072	0.1051521	83.86	16747.737	
Baddeley	0.05	12080	12715.789	116100	122210.53	165.6	174.31579	19226160	9613.08	21	22.105263			0.1051521		1679.12	15968.485	

On the basis of 10% tar production in the process the Baddeley type coal is used
 This coal then provides 9613.08 gas heating value in Btu/lb coal

Baddeley coal gas composition MMt vol% O2 per mole mol O2 per mol gas

CO2 44.01 6.7 0 0

alkyls 31.9988 0 0 0

O2 28.016 25.3 0.5 0.1265

H2 2.0158 21 0.5 0.105

CH4 16.043 1.8 2 0.036

N2 28.013 45.2 0 0

Gas Mwt 23.410686 0.2675 mol O2 per mol gas

Ideal gas density of producer gas 1.045119911 kg/m³ 0.3656313 kg O2 per kg gas

physical data 0.065244718 lb/cuf 1.5800413 kgair/kg gas

Density of Tar 75 lb/cuf Perry 6 (1984)

Units 1200 kg/m³ KO 2 (1964)

scf is volume in cubic feet at 60 Fahrenheit and 30" Hg

density lb/cuf lb/gal Perry 6 (1984)

0.062427974 0.008345406 1

7.480519351 1 119.8264

1 0.133680558 16.01846

mass ton (short - US) lb kg Perry 6 (1984)

1 2000

2.204622962 1

Characteristic value

[illegible]

Acetic acid for Acetic Anhydride synthesis

Concentration of the acid

Source: for all data

Technical report HDC-125-95

Pg 6

By Laurie J. Brown

Holston Defense Corporation

Subsidiary of Eastman Chemical Co.

Kingsport, TN 37660

Product	Conc.	Raw data in lb	kg per kg Acetic acid solution	kg per kg Acetic acid dry base
		3.935	1	1.003009
AcOH	0.997	3.923195	0.997	1
(Water)	0.003	0.011805	0.003	0.003009

Output

Slopwater from flashing		6.652	1.6904701	1.6955568
to IWTF	AcOH	0.05	0.3326	0.0845235
	W	0.95	6.3194	1.6059466

Low Boilers from flashing n-PropylOAc purification
to IWTF

0.2146 0.0545362 0.0547003

Propylformate
MeOAc
Acetone
MeNO3
EthOAc

Sludge from sludge heater		0.02825	0.0071792	0.0072008
to IWTF	AcOH	0.1	0.002825	0.0007179
	Water	0.9	0.025425	0.0064612
	High b.p. materials			0.0064807

condensate to steam plant A

6.264

Inputs

Materials

Acet. anh. acid Conc.

	AcOH	total	3.978647	1.011092	1.0141344
Recover acid	AcOH	0.593	5.884	1.4952986	1.499798
AcAnhd recycle	AcOH	0.795	0.537	0.1364676	0.1368782
Fresh from Malinkrodt	AcOH	0.2	0.3126	0.0794409	0.07968
	Water in solution	total	2.754953	0.7001151	0.7022218
	n-PropylOAc		0.01036	0.0026328	0.0026407
	N2		0.01553	0.0039466	0.0039585
	Filtered Water		6.532	1.6599746	1.6649695
	Steam		15.66	3.9796696	3.9916446
	River Water		77.39	19.66709	19.726269
Energy	Electricity	kWhr	0.02044	0.0051944	0.00521
Waste					
	Water return to river (Non-contact)		77.39	19.66709	19.726269
	Steam Condensate to river (Non-contact)		9.395	2.3875476	2.3947318
Air Emission					
	AcOH		0.004242	0.001078	0.0010813
	n-PropylOAc		0.003653	0.0009283	0.0009311
	N2		0.01553	0.0039466	0.0039585

Acetic acid for Acetic Anhydride synthesis

Purification of spent acid

Source: for all data

Technical report HDC-125-95

Pg 18

By Laurie J. Brown

Holston Defense Corporation

Subsidiary of Eastman Chemical Co.

Kingsport, TN 37660

Product		Conc.	Raw data in lb	kg per kg Acetic acid solution	kg per kg Acetic acid dry base
			5.884	1	1.6666667
	AcOH	0.6	3.5304	0.6	1
	(Water)	0.4	2.3536	0.4	0.6666667
Output					
Condensate			0.09333	0.0158617	0.0264361
to IWTF	AcOH	0.02	0.0018666	0.0003172	0.0005287
	W	0.98	0.0914634	0.0155444	0.0259074
Explosive Slurry			0.4527	0.0769375	0.1282291
to ???	AcOH	0.372	0.1684044	0.0286207	0.0477012
	Water	0.353	0.1598031	0.0271589	0.0452649
	Salts	0.176	0.0796752	0.013541	0.0225683
	Explosive	0.099	0.0448173	0.0076168	0.0126947
ANG-77 mix			0.3733	0.0634432	0.1057387
to ???	Nitrates of Am	0.74	0.276242	0.046948	0.0782467
	Water	0.242	0.0903386	0.0153533	0.0255888
	AcOH	0.005	0.0018665	0.0003172	0.0005287
	Explosive	0.01	0.003733	0.0006344	0.0010574
	Gum	0.003	0.0011199	0.0001903	0.0003172
Inputs					
Materials					
Spent Acid	total		6.073	1.032121	1.7202017
	AcOH	0.603	3.662019	0.622369	1.0372816
	HNO3 salts	0.056	0.340088	0.0577988	0.0963313
	explosives	0.008	0.048584	0.008257	0.0137616
	Water in solu	0.333	2.022309	0.3436963	0.5728272

Acet. anh. acid. Pur.

	NH3		0.01639	0.0027855	0.0046425
	Explosive (RDX)		5.075E-05	8.625E-06	1.438E-05
	Gum		0.00112	0.0001903	0.0003172
	Filtered Water		0.02818	0.0047893	0.0079821
	Steam		4.68	0.7953773	1.3256288
	River Water		62.7	10.656016	17.760027
Energy					
	Electricity	kWhr	0.05474	0.0093032	0.0155053
Waste					
	Water return to river (Non-contact)		62.7	10.656016	17.760027
	Steam Condensate to river (Non-contact)		3.991	0.6782801	1.1304668
Air Emiossion					
	AcOH		0.004242	0.0007209	0.0012016
	n-PropyIOAc		0.003653	0.0006208	0.0010347
	N2		0.01553	0.0026394	0.0043989

Acetic acid treatment and Acetic Anhydride synthesis
 Area A Steam Plant
 Source: for all data
 Technical report HDC-125-95 Pg 24
 By Laurie J. Brown
 Holston Defense Corporation
 Subsidiary of Eastman Chemical Co.
 Kingsport, TN 37660

Product	Steam	Conc.	Raw data in lb	kg per kg Steam	kg per kg Steam	1	1	weighted	according to coal utilization
Output			31.07					0.8858407	
To Block Plant	Cinders		0.2619	0.0084294	0.0074671				
	Fly Ash		0.04937	0.001589	0.0014076				
to IWTF	Boiler blowdown		0.777	0.025008	0.0221531				
with:	Phosphates								
	Sulfates								
	Sulfites								
	Cooling Water		5.413	0.1742195	0.1543307				
with:	fly ash								
	cinders								
Inputs									
Materials	1992 Old numbers	Coal	3.182	0.1024139	0.0907224				
		Coal Tar	0.06779	0.0021818	0.0019328				Eliminated due to replacement of Coal producer gas by NG
	1995 Updated	Coal	3.2313018	0.1040007	0.0921281				Sufficient coal to replace Coal tar heating value
		Air	44.55	1.433859	1.2701707				Assumed to remain the same due to similar H and C balance in Coal and tar
		Boiler water	19.42	0.6250402	0.5538861				
		Condensate	12.43	0.4000644	0.3543933				
		Filtered Water	1.624	0.0522691	0.0463021				
		River Water	3.789	0.1219504	0.1080287				
		Disodium Phosphate	4.922E-05	1.584E-06	1.403E-06				
		Sodium Sulfite	2.538E-05	8.169E-07	7.236E-07				
	Energy	Electricity	0.04629	0.0014899	0.0013198				
	Waste	Fly Ash to Landfill	0.2045	0.0065819	0.0058305				
	Air Emission	VOCs	7.921E-05	2.549E-06	2.258E-06				
		NOx	0.02179	0.0007013	0.0006213				
		CO	0.007954	0.000256	0.0002268				

SOx 0.06045 0.0019456 0.0017235
Particulates 0.0007636 2.458E-05 2.177E-05
Flue gas 47.19 1.5188285 1.3454401

Data from KO 2 (1964) for "modern mechanical method"

	Moisture	Heating valueBtu/lb	Gas		gas heat value		Tar data		lb/lbcoal	energy value btu in tar/lb coal
			dry	Gas yield scf/ton	gas lb/lb coa	Gross heat value Btu/scf	Btu/ton coal	Btu/lb coal		
	wet			wet base	wet base	dry base	wet base	wet base	wet	
Anthracite	0.051	10800	11380.4	123900	130558.48	138	145.41623	17098200	8549.1	0.0475688
Belgian Coa	0.026	11980	12299.795	120900	124127.31	150	154.00411	18135000	9067.5	0.0050072
Baddesley	0.05	12080	12715.789	116100	122210.53	165.6	174.31579	19226160	9613.08	0.1051521
Wet Coal heating value										1679.12
taken as	12000	Btu/lb								Btu/lb tar
										16500
										Characteristic value

Kentucky - Tenn - Ohio Coals
typically 14000 Btu/lb ASTM "Moist"

Coal utilization breakdown for by product distribution

	lb/lb RDX
Coal	3.182
Coal	
Cinders	0.2619
Ash	0.25387
Energy coal	2.66623
Cinder Coal	0.3436
Utilized coal	3.00983
	100.00%

Acetic acid treatment and Acetic Anhydride synthesis

Area A Water filtration

Source: for all data

Technical report HDC-125-95

Pg 28

By Laurie J. Brown

Holston Defense Corporation

Subsidiary of Eastman Chemical Co.

Kingsport, TN 37660

Product	Conc.	Raw data in lb	kg		kg		kg	
			per kg Filtered water	per kg Boiler water	per kg Filtered water	per kg Boiler water		
Filtered water Boiler Water		130.8	1	6.7353244	1	0.8707229		
		19.42	0.1484709	1	0.1292771	1		
		150.22			0.8707229	0.1292771		
Output								
to IWTF	with:	Water	0.6891	0.0052683	0.035484	0.0045873	0.0006811	0.0052683
		Alum	0.02785	0.0002129	0.0014341	0.0001854	2.753E-05	
Inputs	with:	Ion exchange regeneration	1.426	0.0109021	0.0734295	0.0094927	0.0014094	
		H2SO4						
		CaSO4						
		MgSO4						
		NaCl						
		CaCl2						
		MgCl2						
Materials								
	River water	304	2.324159	15.653965	2.0236986	0.3004604		

Acet. anh. IWTP A

Hydrated lime	7.229E-05	5.527E-07	3.722E-06	4.812E-07	7.145E-08
Al Sulfate	0.002363	1.807E-05	0.0001217	1.573E-05	2.335E-06
Cl2	3.999E-05	3.057E-07	2.059E-06	2.662E-07	3.952E-08
H2SO4	0.003582	2.739E-05	0.0001844	2.385E-05	3.54E-06
Rock Salt	0.002891	2.21E-05	0.0001489	1.925E-05	2.857E-06

Energy

Electricity	kWhr	0.1569	0.0011995	0.0080793	0.0010445	0.0001551

Waste

Air Emission

Industrial Wastewater Treatment Facility

Both areas

Source: for all data

Technical report HDC-125-95 Pg 32

By Laurie J. Brown

Holston Defense Corporation

Subsidiary of Eastman Chemical Co.

Kingsport, TN 37660

		Conc.	Raw data in lb	kg per kg wastewater	
Product					
Output					
Inputs					
Materials					
IWTF streams	Wastewater		329.5	1	
	NaOH 20%		0.0314	9.53E-05	
	NaOH	0.2	0.00628	1.906E-05	
	water	0.8	0.02512	7.624E-05	
	Quicklime		0.002363	7.171E-06	
	FeCl ₂ 25-35%		0.01109	3.366E-05	
	FeCl ₂	0.3	0.003327	1.01E-05	
	water	0.7	0.007763	2.356E-05	
	HCl 33%		0.0002453	7.445E-07	
	HCl	0.33	8.095E-05	2.457E-07	
	water	0.67	0.0001644	4.988E-07	
	Magnifloc 496		3.691E-05	1.12E-07	flocculant
	Filtered water		14.96	0.0454021	
Energy					
	Electricity	kWhr	0.2042	0.0006197	
Waste					
	Treated Industrial waste water				
			344.3	1.0449165	
landfill	Biological sludge		0.1533	0.0004653	
landfill	Alum Sludge		0.1154	0.0003502	

Sheet Title:

Acetic Acid (for input at 20% concentration into Holston facility)

Sheet Description:

Engineering calculation (rough)

This page calculates the vendor emissions from a plant producing Acetic acid.

Not included are raw material production or extraction or water and energy use.

(Energy balance is assumed to be close to 0 due to exothermic producer gas synthesis process)

References/Citations:

Faith Keyes and Clarke's Industrial Chemicals

By F. A. Lowenheim, M. K. Moran

Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.

McGraw Hill, 1984

AP 42 Ed 4 (1985)

US EPA

Kirk Othmer Encyclopaedia of Chemical Technology

2nd ED, 1964 and 4th Ed, 1991-4

Wiley Interscience,

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Co-product Quantity Units

Acetic acid 1.00E+00 kg

Coal Tar 1.05E-01 Kg

Total 1.10515212 Kg

Notes:

Bbl eq. are calculated on a energy content basis and used to calculate the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

LCI components

Air

Unallocated		Allocated		Std. Dev.	Quantity	DQI
Units	Quantity	Units	Quantity			
Kg/Kg Acetic a	0.0085	Kg/Kg Acetic a	0.007691249			3
Kg/Kg Acetic a	0.01865878	Kg/Kg Acetic a	0.016883452			3
Kg/Kg Acetic a	0.04618681	Kg/Kg Acetic a	0.041792268			3
Kg/Kg Acetic a	0.11356324	Kg/Kg Acetic a	0.102758018			3
Kg/Kg Acetic a	0.03426683	Kg/Kg Acetic a	0.031006436			3

total HC's

Water

Production wasteKg/Kg Acetic a 0.03599021

Resource Consumption

Coal	Kg/Kg Acetic a	0.47330006	Kg/Kg Acetic a	0.428266893
Methanol	Kg/Kg Acetic a	0.5367573	Kg/Kg Acetic a	0.485686352

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference
BTU	J	1055.056	CRC, 66th Edition
Wh	J	3600	CRC, 66th Edition
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%
gal	L	3.785412	CRC, 66th Edition
kg	lb	2.2046226	CRC, 66th Edition
yr	day	365	
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition
gal CrO	lb CrO	7.2	
ton	lb	2000	
gal fuel oil	BTU fuel oil	138000	
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.
lb Coal (dry)BTU Coal		12000	calculation page B SD=11%
kg NG	MJ NG	46	Calculated page C SD=13%

Calculations

Acetic acid Production

Energy input

All energy is assumed to come from the heat of combustion in the formation of CO, which is recoverable.

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Coal	MJ/kg ethylene	0			3 kg/kg ethylene	0	
Oil	MJ/kg ethylene	0	15		3 kg/kg ethylene	0	0.33622909
Natural Gas	MJ/kg ethylene	0			3 kg/kg ethylene	0	
Hydropower	MJ/kg ethylene	0			3		

Material input

Source: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Methanol Carbonylation method

Stoichiometric ratios:

Methanol net	Kg/Kg Acetic a	0.533	
CO net	Kg/Kg Acetic a	0.467	
Methanol input	Kg/Kg Acetic a	0.5367573	0.993 0.993 conversion of methanol
CO input	Kg/Kg Acetic a	0.51318681	0.91 0.91 conversion of CO
Producer-Gas input	Kg/Kg Acetic a	1.69497376	from Faith Keyes and Clark's Industrial chemicals, 1975
Coal input	Kg/Kg Acetic a	0.47330006	

Emission calculation (Data from pg D and from AP42 Ed 4 Tbl 1.1-1)

Air			
CO released from process	Kg/Kg Acetic a	0.04618681	0.09 unconverted CO
Methane	Kg/Kg Acetic a	0.03050953	
CO2	Kg/Kg Acetic a	0.11356324	
Particulates	Kg/Kg Acetic a	0.0085	8.5 g/kg in Cyclone trap outlet (AP42 Ed 4 tbl 1.1-1)
Methanol	Kg/Kg Acetic a	0.0037573	0.007 unconverted assumed to escape in vent stream
SOx	Kg/Kg Acetic a	0.01865878	19.5*S in Co from AP 42 Ed 4 (1985) tbl 1.1-1 Coal assumed to have 1% Sulfur and the coal tar product to have 0.4% sulfur
Land			
Ash	Kg/Kg Acetic a	0.03599021	0.094 Ash in coal (assumed recovered) but for air emission

CO production from Coal through synthesis gas (producer or manufactured)

Source: Page D calculations

Producer gas from Coal (Baddelsey)
25.30% mol CO 30.28% wt CO

Mw CO 28.016
Mw Produc 23.410686

Gas product yield from coal: 3.58118218 lb gas/lb coal

Co-Products:

source: calculated from data on this sheet and on sheet D
Coal tar heating value is median for data of Perry Ed 6 (1984) tbl. 9-12

Coal Tar Kg/Kg Acetic a 0.10515212

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil							
Natural Gas							
Coal	Kg/Kg Acetic a	0.47330006			Kg/Kg Acetic acid	0.47330006	
Iron ore	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Methanol	Kg/Kg Acetic a	0.5367573			Kg/Kg Acetic acid	0.5367573	
Bauxite	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Rock salt	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Clay	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Output							
Air							
LCI component							
TSP	Kg/Kg Acetic a	0.0085			Kg/Kg Acetic acid	0.0085	
SOx	Kg/Kg Acetic a	0.01865878			Kg/Kg Acetic acid	0.01865878	
NOx	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
CO	Kg/Kg Acetic a	0.04618681			Kg/Kg Acetic acid	0.04618681	
CO2	Kg/Kg Acetic a	0.11356324			Kg/Kg Acetic acid	0.11356324	
H2S	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
HCl	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
total HC's	Kg/Kg Acetic a	0.03426683			Kg/Kg Acetic acid	0.03426683	
other organic	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Heavy metals	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Water							
LCI component							
COD	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
BOD	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Acid as H+	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Metal ions	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Cl2	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Dissolved Organics	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

suspended solids	Kg/Kg Acetic acid	0	Kg/Kg Acetic acid	0
crude oil	Kg/Kg Acetic acid	0	Kg/Kg Acetic acid	0
miscellaneous dissolved materials	Kg/Kg Acetic acid	0	Kg/Kg Acetic acid	0
Phenol	Kg/Kg Acetic acid	0	Kg/Kg Acetic acid	0
Solid waste				

LCl component	Raw/		Raw/		DQI	Transformed		Transformed	
	Input Units	Input Quan.	Input Std. Dev.	Input Std. Dev.		Units	Quan.	Std. Dev.	Std. Dev.
Production waste (not in net)	Kg/Kg Acetic acid	0.03599021				Kg/Kg Acetic acid	0.00128		
Toxic chemicals	Kg/Kg Acetic acid	0				Kg/Kg Acetic acid	0.000001		

Sheet Title: MEK (from sec-butanol which is from n-butene which is a byproduct of butadiene production from ethylene. MEK is used in production of TNAZ)

Sheet Description: Emissions are from TRI database.
Engineering calculation of the Energy requirements and precursor requirements.
This page calculates the vendor emissions from a plant producing PCI3.
Not included are raw material production or extraction or water use.

References/Citations: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowerheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11, 1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11, 1994

Mwt	Co-product	Quantity	Units	Quantity	Units
137.329	PCI3	1.00E+00	Kg	1.00E+00	kg
Total		1.00E+00	Kg	1.00E+00	Kg

Notes:

LCI components		Unallocated	Quantity	Std. Dev.	Allocated	Quantity	Std. Dev.	DQI
		Units			Units			
Air	Cl2	Kg/kg MEK	4.18147E-06		Kg/kg MEK	4.18147E-06		3
	Zinc oxides/Phos	Kg/kg MEK	1.136721242		Kg/kg MEK	1.136721242		3
	Water							
Dissolved Organ		Kg/kg MEK	1.73292E-05		Kg/kg MEK	1.73292E-05		3
Solid Wastes								
in containerP4 production w		Kg/kg MEK	5.85013E-07		Kg/kg MEK	5.85013E-07		
Zinc Compounds		Kg/kg MEK	3.80251E-05		Kg/kg MEK	3.80251E-05		

Resource Consumption
Chlorine Kg/kg MEK 1.73292E-05 Kg/kg MEK 1.73292E-05

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors		
Unit from	Unit to	Multiplier
BTU	J	1055.056 CRC, 66th Edition
Wh	J	3600 CRC, 66th Edition
bbl CrO	BTU CrO	5800000 Chemical Engineers' Handbook, 6th ed.
bbl	gal	42 Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	118500 Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%
gal	L	3.785412 CRC, 66th Edition
kg	lb	2.2046226 CRC, 66th Edition
yr	day	365
m ³	bbl (petroleum)	6.289811 CRC, 66th Edition
gal CrO	lb CrO	7.2
ton	lb	2000
gal fuel oil	BTU fuel oil	138000
cu. ft NG	BTU NG	1032 Chemical Engineers' Handbook, 6th ed.
lb Coal (dry) BTU Coal		12000 calculation page B SD=11%
kg NG	MJ NG	46 Calculated page C SD=13%
Mw Benzen	78.1134	molar
Mw Chlorin	70.9	dry air composition
Mw ClBz	112.56	N2
Mw Cl2Bz	147.01	O2
Mw HCl	36.4609	CO2
Mw NaOH	39.9971	Ar
		total
		0.99997
		28.96409
		1
		kg air per kg mass composition component
		28.0134
		0.75521
		0.231406
		0.000501
		0.012882
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The Norco Plant of Shell produces ethylene and propylene and some butylene from mixed LPG (ethane and propane) feedstocks and then manufactures derivatives of butenes into MEK. Production data includes captive production and therefore all relevant emissions may be attributed to that quantity.

The following reported emissions were deemed unrelated to MEK product. Allyl Cl
The following reported emissions were ascribed to MEK production only: MEK
Emissions allocated between the products (cracker by products) styrene

Energy and material input data from the calculations of sheet "Calc"

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Fossil fuel (general)	MJ/kg PC13	0			MJ/kg PC13	0	
Coal	MJ/kg PC13	0			Kg/kg MEK	0	
Oil	MJ/kg PC13	0	15		Kg/kg MEK	0	
Natural Gas	MJ/kg PC13	0			Kg/kg MEK	0	
Hydropower	MJ/kg PC13	0					
Fission	MJ/kg PC13	0					
Electricity (generic)	MJ/kg PC13	2.88758E-07			MJ/kg P4	2.88758E-07	
Material Input						Probably different mix in US	

Co-Products:
source:

See from above

Resources:

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil	Kg/kg MEK	0			4 Kg/kg MEK	0	
Natural Gas	Kg/kg MEK	0			4 Kg/kg MEK	0	
Coal	Kg/kg MEK	0			4 Kg/kg MEK	0	
Naphtha	lb/Shell, Norco	431616341			4 Kg/kg MEK	1.879888255	
ammonia	Kg/kg MEK	1.73292E-05			4 Kg/kg MEK	1.73292E-05	
Silicate (sand)	Kg/kg MEK	0			4 Kg/kg MEK	0	
Air	Kg/kg MEK	0			4 Kg/kg MEK	0	
Water	Kg/kg MEK	0			4 Kg/kg MEK	0	

(all into water emission)

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/kg MEK	0			Kg/kg MEK	0	
SOx	lb/Shell, Norco	0			Kg/kg MEK	0	
NOx	lb/Shell, Norco	0			Kg/kg MEK	0	
Cl2	lb/Shell, Norco	960			Kg/kg MEK	4.18147E-06	
CO2	Kg/kg MEK	0			3 Kg/kg MEK	0	
P4	lb/Shell, Norco	0			Kg/kg MEK	0	
Styrene	lb/Shell, Norco	1.136721242			Kg/kg MEK	4.95121E-09	
toluene	lb/Shell, Norco	878.375505			Kg/kg MEK	3.82593E-06	
propylene	lb/Shell, Norco	2898.639166			Kg/kg MEK	1.26256E-05	
xylylene	lb/Shell, Norco	129.9479056			Kg/kg MEK	5.66013E-07	
ammonia	lb/Shell, Norco	7.233680629			Kg/kg MEK	3.15077E-08	
sulfuric acid	lb/Shell, Norco	126.8994259			Kg/kg MEK	5.52735E-07	
titanium tetrachloride	lb/Shell, Norco	191.2791835			Kg/kg MEK	8.33153E-07	
naphthalene	lb/Shell, Norco	82.67063576			Kg/kg MEK	3.60088E-07	
MEK	lb/Shell, Norco	68000			Kg/kg MEK	0.000296187	
Methyl iso butyl ketone	lb/Shell, Norco	15			Kg/kg MEK	6.53354E-08	

sec-butyl alcohol	lb/Shell, Norco	81000		Kg/kg MEK	0.000352811
Acetone	lb/Shell, Norco	850		Kg/kg MEK	3.70234E-06
HC total	lb/Shell, Norco	154181.1822		Kg/kg MEK	0.000671586
Heavy metals (Cd+Ni+Cr)	lb/Shell, Norco	0		Kg/kg MEK	0

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	lb/Shell, Norco	0			5 Kg/kg MEK	0	
BOD	lb/Shell, Norco	0			5 Kg/kg MEK	0	
Acid, H+ (Phosphoric)	lb/Shell, Norco	0			5 Kg/kg MEK	0	
Metal ions	lb/Shell, Norco	0			5 Kg/kg MEK	0	
Cl2	lb/Shell, Norco	0			5 Kg/kg MEK	0	
Ammonia	lb/Shell, Norco	3578.524346			5 Kg/kg MEK	1.73292E-05	
suspended solids	lb/Shell, Norco	0			5 Kg/kg MEK	0	
crude oil	lb/Shell, Norco	0			5 Kg/kg MEK	0	
miscellaneous dissolved mate	lb/Shell, Norco	0			5 Kg/kg MEK	0	
Phenol	lb/Shell, Norco	0			5 Kg/kg MEK	0	

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not inert)	lb/Shell, Norco	134.3100149			5 Kg/kg MEK	5.85013E-07	
Total no catalyst	lb/Shell, Norco	8725.971082			5 Kg/kg MEK	3.80251E-05	
styrene	lb/Shell, Norco	8.78375505			6 Kg/kg MEK	3.82593E-08	
toluene	lb/Shell, Norco	51.66914735			7 Kg/kg MEK	2.25055E-07	
xylene	lb/Shell, Norco	5.683606209			8 Kg/kg MEK	2.4758E-08	
sulfuric acid	lb/Shell, Norco	25.83457368			9 Kg/kg MEK	1.12527E-07	
titanium tetrachloride	lb/Shell, Norco	14054.00808			10 Kg/kg MEK	6.12149E-05	
MEK	lb/Shell, Norco	3000			11 Kg/kg MEK	1.30671E-05	
Methyl iso butyl ketone	lb/Shell, Norco	30			12 Kg/kg MEK	1.30671E-07	
Acetone	lb/Shell, Norco	5608			13 Kg/kg MEK	2.44267E-05	
Heavy metals (Cadmium, Ni)	lb/Shell, Norco	0			5 Kg/kg MEK	0	

Sheet End

Source: SRI Directory of Chemical Producers, US
1993, edition
SRI International, Menlo Park, CA

[illegible]

MEK Product distribution

xylene	2515		110	129.9479		5.683606
ammonia	140	77000		7.233681	3978.5	
sulfuric acid	2456		500	126.8994		0.3100149
titanium tetrachloride	3702		272000 reclamation	191.2792		25.83457
naphthalene	1600			82.67064		14054.01

Sheet Description: This page calculates the vendor-independent emissions from european refineries producing monomer quality butylene Included are oil extraction and transportation from the well head to the refinery.

References/Citations: SimaPro3 (entry of Nov 18 94)
Average data for 19 european cracking facilities producing monomer quality ethylene.
taken from:
PWWI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Summary Output

Co-product	Quantity	Units

butylene	1.00E+00	Kg

Total 1 Kg

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
TSP	Kg/Kg butylene	0.0008					3
SOx	Kg/Kg butylene	0.004					3
NOx	Kg/Kg butylene	0.006					3
CO	Kg/Kg butylene	0.0004					3
CO2	Kg/Kg butylene	0.5					3
H2S	Kg/Kg butylene	0.000001					3
HCl	Kg/Kg butylene	0.00001					3
total HC's	Kg/Kg butylene	0.007					3
other organic	Kg/Kg butylene	0.000001					3
Heavy metals	Kg/Kg butylene	0.000001					3
Water							
COD	Kg/Kg butylene	0.0002					3
BOD	Kg/Kg butylene	0.00004					3
Acid as H+	Kg/Kg butylene	0.00004					3
Metal ions	Kg/Kg butylene	0.0003					3
Cl2	Kg/Kg butylene	0.00005					3

Dissolved Organ	Kg/Kg butylene	0.00002	3
suspended solid	Kg/Kg butylene	0.0002	3
crude oil	Kg/Kg butylene	0.0001	3
miscellaneous dis	Kg/Kg butylene	0.0004	3
total HC's	Kg/Kg butylene	0.00009	
Phenol	Kg/Kg butylene	0.000001	3
Solid Wastes			
Production waste	g/Kg butylene	0.0083	3
Resource Consumption			
Natural Gas	Kg/Kg butylene	0.533478261	3
Natural Gas	Kg/Kg butylene	0.143913043	#VALUE!
Crude Oil	Kg/Kg butylene	0.789017599	#VALUE!
Crude Oil	Kg/Kg butylene	0.036088589	#VALUE!
Coal	Kg/Kg butylene	0.000358269	
Coal	Kg/Kg butylene	0.017196902	3
Hydropower	MJ/Kg butylene	0.06	
Fission	MJ/Kg butylene	0.22	
Iron ore	Kg/Kg butylene	0.0002	
limestone	Kg/Kg butylene	0.0001	
Bauxite	Kg/Kg butylene	0.0003	
Rock salt	Kg/Kg butylene	0.006	
Clay	Kg/Kg butylene	0.00002	
Water	Kg/Kg butylene	1.6	

Notes: This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors			
Unit from	Unit to	Multiplier	Reference
BTU	J	1055.056	CRC, 66th Edition
Wh	J	3600	CRC, 66th Edition
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	119500	Chemical Engineers' Handbook, 6th ed.
gal	L	3.785412	CRC, 66th Edition
kg	lb	2.2046226	CRC, 66th Edition
yr	day	365	
m ³	bbl (petroleum)	6.289811	CRC, 66th Edition
gal CrO	lb CrO	7.2	

ton	lb	2000
gal fuel oil	BTU fuel oil	138000
cu. ft NG	BTU NG	1032
lb Coal (dry)	BTU Coal	12000
kg NG	MJ NG	46

Chemical Engineers' Handbook, 6th ed.
SD=11%
SD=13%

Calculations

Ethylene Production

	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
LCI component butylene (polymer)	1 Kg				3		
butylene (other)							

SimaPro3

Average data for 19 european cracking facilities producing monomer quality butylene.
taken from:

PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Energy input

	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
LCI component							
Coal	MJ/Kg butylene	0.48			3 Kg/Kg butylene	0.017196902	
Oil	MJ/Kg butylene	1.61			3 Kg/Kg butylene	0.036088589	
Natural Gas	MJ/Kg butylene	6.62			3 Kg/Kg butylene	0.143913043	
Hydropower	MJ/Kg butylene	0.06			3 MJ/Kg butylene	0.06	
Fission	MJ/Kg butylene	0.22			3 MJ/Kg butylene	0.22	
						Probably different mix in US	

Material input

	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
LCI component							
Oil	MJ/Kg butylene	35.2			3 Kg/Kg butylene	0.789017599	
Natural Gas	MJ/Kg butylene	24.54			3 Kg/Kg butylene	0.533478261	
Coal	MJ/Kg butylene	0.01			3 Kg/Kg butylene	0.000358269	
Iron ore	Kg/Kg butylene	0.0002			3 Kg/Kg butylene	0.0002	
limestone	Kg/Kg butylene	0.0001			3 Kg/Kg butylene	0.0001	
Bauxite	Kg/Kg butylene	0.0003			3 Kg/Kg butylene	0.0003	
Rock salt	Kg/Kg butylene	0.006			3 Kg/Kg butylene	0.006	
Clay	Kg/Kg butylene	0.00002			3 Kg/Kg butylene	0.00002	
Water	Kg/Kg butylene	1.6			3 Kg/Kg butylene	1.6	

Output
Air

Raw/	Raw/	Raw/	Transformed	Transformed

LCI component	Input Units	Input Quan.	Input Std. Dev.	DQI	Units	Quan.	Std. Dev.
TSP	Kg/Kg butylene	0.0008			Kg/Kg butylene	0.0008	
SOx	Kg/Kg butylene	0.004			Kg/Kg butylene	0.004	
NOx	Kg/Kg butylene	0.006			Kg/Kg butylene	0.006	
CO	Kg/Kg butylene	0.0004			Kg/Kg butylene	0.0004	
CO2	Kg/Kg butylene	0.5			Kg/Kg butylene	0.5	
H2S	Kg/Kg butylene	0.000001			Kg/Kg butylene	0.000001	
HCl	Kg/Kg butylene	0.00001			Kg/Kg butylene	0.00001	
total HC's	Kg/Kg butylene	0.007			Kg/Kg butylene	0.007	
other organic	Kg/Kg butylene	0.000001			Kg/Kg butylene	0.000001	
Heavy metals	Kg/Kg butylene	0.000001			Kg/Kg butylene	0.000001	
Water							

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg butylene	0.0002			Kg/Kg butylene	0.0002	
BOD	Kg/Kg butylene	0.00004			Kg/Kg butylene	0.00004	
Acid as H+	Kg/Kg butylene	0.00004			Kg/Kg butylene	0.00004	
Metal ions	Kg/Kg butylene	0.0003			Kg/Kg butylene	0.0003	
Cl2	Kg/Kg butylene	0.00005			Kg/Kg butylene	0.00005	
Dissolved Organics	Kg/Kg butylene	0.00002			Kg/Kg butylene	0.00002	
suspended solids	Kg/Kg butylene	0.0002			Kg/Kg butylene	0.0002	
crude oil	Kg/Kg butylene	0.0001			Kg/Kg butylene	0.0001	
miscellaneous dissolved mater	Kg/Kg butylene	0.0004			Kg/Kg butylene	0.0004	
HC's	Kg/Kg butylene	0.00009			Kg/Kg butylene	0.00009	
Phenol	Kg/Kg butylene	0.000001			Kg/Kg butylene	0.000001	
Solid waste							
Production waste (not inert)	Kg/Kg butylene	0.0083			Kg/Kg butylene	0.0083	

Sheet End

Butylene Coal

Coal type	Moisture %	Sulfur %	%dry	Heat value Btu/lb	Btu/lbdry	
Sub bit C	26	0.3	0.41	8230	11121.622	
HV bit A	2.9	0.6	0.62	14170	14593.203	low sulfur coal heating value
Sub bit B	22.2	0.5	0.64	9610	12352.185	
Brown Coal	55	0.3	0.67	4830	10733.333	
Sub bit A	13.9	0.6	0.70	10330	11997.677	SD= 1295.7751 0.1081691
Meta Anthracite	9	0.7	0.77	10080	11076.923	Avg= 11979.157
LV bit	2.9	0.8	0.82	14400	14830.072	median
Anthracite	4.3	0.8	0.84	12880	13458.725	
Lignite	36.8	0.9	1.42	7000	11075.949	
MV bit	2.4	1.5	1.54	14490	14846.311	
Semi anthracite	2.1	1.7	1.74	13700	13993.871	
HV bit B	6.7	2.6	2.79	12390	13279.743	
HV bit C	15.4	2.9	3.43	10740	12695.035	

bit=Bituminous

V=Volatility

L=low

M=Medium

H=high

Source: Kirk Othmer vol 4 1949

Natural gas

Mwt heat value Rio Arriba, N Terrell, Tex Stanton, KanSan Juan, NMIds Field, A Cliffside, Texas

mol% MJ/M³

Methane	16.043	37.57	96.91	45.64	67.56	77.28	52.34	65.8			
ethane	30.07	65.83	1.33	0.21	6.23	11.18	0.41	3.8			
propane	44.097	93.6	0.19		3.18	5.83	0.14	1.7			
butane	58.123	120.98	0.05		1.42	2.34	0.16	0.8			
pentane+	72.15	148.84	0.02		0.04	1.18	0.41	0.5			
CO2	44.01	0	0.82	53.93	0.07	0.8	8.22		avg	SD (rel)	
H2S	34.076	23.7		0.01			35.79		19.610242	10.79%	
N2	28.013	0	0.68	0.21	21.14	1.39	2.53	25.6	39.766667	12.81%	
Mol wt:			16.625849	31.182	20.921258	21.28362	25.492892	20.445665	45.760008	13.03%	
heating value	MJ/M ³		37.6	17.3	34.9	46.8	30	30.7			
MJ/KG			50.658467	12.427683	37.366777	49.254778	26.360289	33.634514			

0.0224M³/mol

too high
CO2
content for
use

too high
Sulfur
content

too low
heating
value(?)

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m³

Heating values for processed city natural gas:

source Perry 6 (1964)

averaged from table 9-14

Btu/scf 1049.5714

Synopsis of table 9-14

mol%	Mwt	heat value MJ/M ³	Baltimore Md	Columbus Ohio	Houston Tx	Birmingham Al	Washington DC	Phoenix Az
Methane	16.043	37.57	94.4	93.14	92.5	93.14	95.15	87.37

Butylene NG

ethane	30.07	65.83	3.4	3.58	4.8	2.5	2.84	8.11		
propane	44.097	93.6	0.6	0.66	2	0.67	0.63	2.26		
butane	58.123	120.98	0.5	0.22	0.3	0.32	0.24	0.13		
pentane+	72.15	148.84	0	0.09	0	0.12	0.05	0		
CO2	44.01	0	0.6	0.85	0.27	1.06	0.62	0.61		
H2S	34.076	23.7		0.01						
N2	28.013	0		0.21	21.14	2.14	0.42	1.37		
Mol wt:			17.126294	16.939122	23.380219	17.328208	16.9628	18.179837	avg	SD (rel)
heating value	MJ/M^3		39.2023	38.3444	38.4563	38.1952	38.8666	39.9483	18.319413	15.84%
	MJ/KG		51.273879	50.705967	36.844014	49.374551	51.324771	49.221668	38.835517	1.10%
									48.124142	13.30%

0.0224M^3/mol

Sheet Title: MTBE (from Methanol and Isobutylene. MTBE is used in production of TNAZ)

Sheet Description: Emissions are from TRI database.
Engineering calculation of the Energy requirements.
Precursor material requirements are from EIA.
This page calculates the vendor emissions from a plant producing MTBE.
Not included are raw material production or extraction or water use.

References/Citations: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

Mwt	Co-product	Quantity	Units	Quantity	Units	BP deg C	Sp G	Vapor density relative to air
88.1492	MTBE	1.00E+00	kg	1.00E+00	kg	8.2	1.392	3.4
	Total	1.00E+00	Kg	1.00E+00	Kg			

Notes:

LCI components	Unallocated	Quantity	Std. Dev.	Allocated	Quantity	Std. Dev.	DQI
Air							
MTBE	Kg/kg MTBE	7.31922E-06		Kg/kg MTBE	7.31922E-06		5
Methanol	Kg/kg MTBE	2.13838E-05		Kg/kg MTBE	2.13838E-05		5
Ammonia	Kg/kg MTBE	4.09116E-09		Kg/kg MTBE	4.09116E-09		5
Water							
MTBE	Kg/kg MTBE	3.25744E-08		Kg/kg MTBE	3.25744E-08		5
Methanol	Kg/kg MTBE	5.42907E-06		Kg/kg MTBE	5.42907E-06		5
Ammonia	Kg/kg MTBE	1.65873E-07		Kg/kg MTBE	1.65873E-07		5
Solid Wastes							

Resource Consumption

Electric Power	MJ/Kg MTBE	9.94219E-08	MJ/Kg MTBE	9.94219E-08
Isobutylene	Kg/kg MTBE	0.844445946	Kg/kg MTBE	0.844445946
Methanol	Kg/kg MTBE	0.273010811	Kg/kg MTBE	0.273010811

3
5
5

Notes:

This section is where the project specific calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multipplier	Reference
BTU	J	1055.056	CRC, 66th Edition
Wh	J	3600	CRC, 66th Edition
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed.
gal	L	3.785412	CRC, 66th Edition
kg	lb	2.2046226	CRC, 66th Edition
yr	day	365	
p.s.i.	feet water	2.03686	CRC, 66th Edition
m ³	bbl (petroleum)	6.289811	CRC, 66th Edition
gal CrO	lb CrO	7.2	
ton	lb	2000	
gal fuel oil	BTU fuel oil	138000	
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.
lb Coal (dry)	BTU Coal	12000	calculation page B
kg NG	MJ NG	46	Calculated page C
d MTBE	0.74 rel to Water	molar	
Mw Chlorin	70.9	dry air composition	
Mw ClBz	112.56	N2	0.78084
Mw ClBz	147.01	O2	0.20946
Mw HCl	36.4609	CO2	0.00033
Mw NaOH	39.9971	Ar	0.00934
		total	0.99997
			28.96409
			1
			kg air per kg
			mass composition component
			0.75521
			1.324134
			0.231406
			4.321406
			0.000501
			1994.319
			0.012882
			77.62792

Ideal gas density at 15 C (60 F)
0.042296 mol/liter

42.29634021 mol/m³
air (dry)

1.225075005 kg/m³

Calculations

MTBE Production

Source: US ITC 2810 11.94 Synthetic Organic Che Kg 1993
US Production and Sales, 1993 5547491608 5547491608

MTBE production capacity

Source: SRI 1993 Directory of Chemical Producers, US

Utilization ratio: Mlb 15149
chemical industry average 199 0.80732229
Capacity Mlb
Calculated production: Mlb
Global Octanes Corporation Deer Park, Tx 1150 928 4206337

333 268.8383226

Baton Rouge, LA 70821

Exxon

Source: Emissions:

TRI database, 1993 data
The Van de Mark plant is the only manufacturer of MTBE for open sale on the market so only its TRI data are used

The following reported emissions were ascribed to MTBE production only: MTBE Methanol Isobutylene Cr Ammonia

4
154

Global Octanes Corporation

Air 3.00E+00 2.00E+00
Water 0.00E+00 0.00E+00
Air 8.76E+03 2.56E+04
Water 3.90E+01 6.50E+03

Exxon

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Fossil fuel (general)	MJ/kg MTBE	0	0		MJ/kg MTBE	0	
Coal	MJ/kg MTBE	0	0		Kg/kg MTBE	0	
Oil	MJ/kg MTBE	0	0		Kg/kg MTBE	0	
Natural Gas	MJ/kg MTBE	0	0		Kg/kg MTBE	0	
Hydropower	MJ/kg MTBE	0	0				
Fission	MJ/kg MTBE	0	0				
Electricity (generic)	MJ/kg MTBE	9.94219E-08			MJ/kg MTBE	9.94219E-08	

Cooling
water

25 deg C temp rise
0 heat removal MJ/kg water
0 MJ/kg product
0 Kg/kg product

0.7 efficiency

7.87E-05 kJ Elec/Kg Based on viscosity and density of water for a 250 ft static head per pumping stage
in 40hr week & 52 week year daytime operation. multiply by specific gravity of material
and relative viscosity to that of water.

representative m Sp grav Sp visc kgflow/kg prod
to wash, toMTBE 0.74 0.233 MJ/kg MTBE 1.35739E-08 viscosity of EE ether
to reactor Methanol to P=20 0.791 0.597 MJ/kg MTBE 7.87077E-08
to reactor Isobutylene P to 0.5942 0.223 MJ/kg MTBE 7.14023E-08
cooling water CRC 66 1 1 0 9.94219E-08 total pumping energy
per kg prod
MTBE from Hawley's

376.7821

200 psi =

2 5.5 8 8 1 24.5
6 2.5 7 15.5Co-Products:
source:

See from above

Resources: Faith, Keyes and Clark's Industrial chemicals

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil	Kg/kg MTBE	0	0		Kg/kg MTBE	0	
Natural Gas	Kg/kg MTBE	0	0		Kg/kg MTBE	0	
Coal	Kg/kg MTBE	0	0		Kg/kg MTBE	0	
29.0183 Methanol	Gall/Gal MTBE	0.79			5 Kg/kg MTBE	0.844445946	

US Petroleum refining "Meeting Requirements for Cleaner Fuels and Refineries"

Ion exchange resin (acidic)

Kg/kg MTBE

0

?

5 Kg/kg MTBE

0

Air

Kg/kg MTBE

0

0

Kg/kg MTBE

0

Water

Kg/kg MTBE

0

0

Kg/kg MTBE

0

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/kg MTBE	0	0		Kg/kg MTBE	0	0
SOx	Kg/kg MTBE	0	0		Kg/kg MTBE	0	0
NOx	Kg/kg MTBE	0	0		Kg/kg MTBE	0	0
Cl2	Kg/kg MTBE	0	0		Kg/kg MTBE	0	0
CO2	Kg/kg MTBE	0	0		3 Kg/kg MTBE	0	0
MTBE	Kg/kg MTBE	8.76E+03	0		Kg/kg MTBE	7.31922E-06	0
Methanol	Kg/kg MTBE	2.56E+04	0		Kg/kg MTBE	2.13838E-05	0
Ammonia	Kg/kg MTBE	4.90E+00	0		Kg/kg MTBE	4.09116E-09	0
HC total	Kg/kg MTBE	0	0		Kg/kg MTBE	0	0
Heavy meta(Cd+Ni+Cr)	Kg/kg MTBE	0	0		Kg/kg MTBE	0	0

Industrial practice is to leave excess C

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	lb/Exxon +Glob	0	0		5 Kg/kg MTBE	0	0
BOD	lb/Exxon +Glob	0	0		5 Kg/kg MTBE	0	0
Acid, H+ (Phosphoric)	lb/Exxon +Glob	0	0		5 Kg/kg MTBE	0	0
Metal ions	lb/Exxon +Glob	0	0		5 Kg/kg MTBE	0	0
Cl2	lb/Exxon +Glob	0	0		5 Kg/kg MTBE	0	0
CO2	lb/Exxon +Glob	0	0		5 Kg/kg MTBE	0	0
MTBE	lb/Exxon +Glob	3.90E+01	0		5 Kg/kg MTBE	3.25744E-08	0
Methanol	lb/Exxon +Glob	6.50E+03	0		5 Kg/kg MTBE	5.42907E-06	0
Ammonia	lb/Exxon +Glob	198.5930435	0		5 Kg/kg MTBE	1.65873E-07	0
Heavy metals (Cadmium, Nidbi/Exxon +Glob		0	0		5 Kg/kg MTBE	0	0

Exxon plant uses ammonia predominantly for other purposes

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not inert)lb/Exxon +Glob		0	0		5 Kg/kg MTBE	0	0
Heavy metals (Cadmium, Nidbi/Exxon +Glob		0	0		5 Kg/kg MTBE	0	0

Offsite Transfer

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DOI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Chromium (catalyst?)	lb/Exxon +Glob	541580	0		Kg/kg MTBE	0.00045235	0

Corn Production Last Modified 10/06/95

Sheet Title:

Sheet Description:

This page includes calculations of the average resource consumption and emissions from the production of corn in the United States. This includes information on the embodied energy in materials used such as fertilizers, pesticides and insecticides, lime, and seed. It does not include embodied energy to manufacture farm machinery or buildings. All basic data is converted into units of input or output per bushel (bu) of corn output.

Many of the calculations below are adjusted to account for the relationship of harvested to planted acres. Typically, only about 98-99% of planted corn acres are harvested. Some resources have gone into this planting however, such as seed, fertilizer, energy, etc. For this reason, yields and resource consumption are adjusted to account for unharvested acreage.

Air emissions are also broken out by source in the columns to the right of the allocated emissions. These are expressed both as quantity per bushel, and as a percentage of total emissions. In this way the most important sources of air emissions can be identified, and the veracity of the estimates checked.

Also provided in a table to the right are some other recent estimates of energy use to produce corn, and a discussion of why the results of the studies vary. Fortunately, though estimates of energy use for particular inputs vary considerably, this variation in most cases is cancelled out, use at least some fairly crude assumptions about distances and modes hauled. Lacking further in that the overall energy intensity values are fairly consistent. It is hoped that the detailed methodology followed below is not only accurate, but as consistent with the estimate in Lorenz, and probably derives from the same original data. Energy resource use data important to the assessment of secondary impacts (e.g. emissions from fertilizer manufacture).

Note: Blanchard estimates that 1-3% of corn is removed in the cleaning process at the mill. Since this corn is used in feed, the corn balance presented in the corn refining material balance accounts for this loss.

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Energy Use in Corn Production

Item	Shapouri et al	Lorenz et al	19 This Study
Nitrogen	22,631	28,295	23,866
Potash	539	2,390	956
Phosphate	1,992	2,417	1,635
Lime	1,232	-	748
Chemicals	5,766	2,704	2,697
All Other	23,024	33,386	24,049
Total	55,184	69,192	53,952

Notes: Both this study and Shapouri rely on the same source of information for on-farm energy use is lumped into the category "other" and it can be seen that the two estimates are very close. S for pesticides from Pimentel (1991) which appears to find its genesis in another Pimentel work (19 to come from Pimentel 1991, but may come from Pimentel 1988, where it is cited at 100 KJ/kg. C that it includes energy for formulation, packaging, and transport. Shapouri adds energy use for inp the counting. The 1980 estimate for packaging, formulation, and transport is also much higher than co use at least some fairly crude assumptions about distances and modes hauled. Lacking further in quantity precisely. Each form of fertilizer requires different amounts of energy. Both Shapouri and that were aggregated up from fertilizer type specific data. In this report fertilizer type specific data the types of fertilizers used with corn to develop a corn specific value. In any case, the estimates higher than those used by Shapouri and this report, however they include transportation, packagi The packaging, transportation, and application estimates were derived from a source specifically fertilizer is sold in bulk, these estimates themselves may be high. Lorenz also uses a very high es from an estimate that 16% of corn is irrigated. Both this report and the Shapouri report use data fr use (including irrigation). Since the fraction of corn irrigated in the midwest is very small, this may intensity estimates.

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Summary Output:

Allocated LCI components		Units	Quantity	DQI	Notes:
Air	Fertilizer N2O	lb/bu	0.0132	3	Survey of study results.
	Fertilizer NO	lb/bu	0.0081	1	Based on only one study.
	NOx	lb/bu	4.26E-02	2	Some general emission factors used
	SOx	lb/bu	2.03E-02	2	Some general emission factors used
	PM-10	lb/bu	3.62E-01	3	Driven by fugitive emissions from tilling for which current data is available.
	CO	lb/bu	1.53E-01	4	Driven by CO emission from gas tractors for which current data is available.
	CO2	lb/bu	6.93E+00	4	Good quality data
	Non-Methane Organic Qa/bu	lb/bu	2.33E-02	3	Dominated by VOC's used in pesticides. Relatively well characterized.
	Methane	lb/bu	1.98E-05	2	Some general emission factors used
	Particulate	lb/bu	4.48E-03	2	Some general emission factors used
	Hydrocarbons	lb/bu	1.00E-02	3	Fairly current and specific data on farm machinery emissions.
	Aldehydes	lb/bu	4.70E-04	3	Fairly current and specific data on farm machinery emissions.
	Ammonia	lb/bu	1.42E-02	2	Dominated by emissions from ammonium nitrate manufacture, for which factors given as a very broad range. Thus point estimate may be poor.
	Nitric Acid	lb/bu	1.97E-04	2	Dominated by emissions from ammonium nitrate manufacture, for which factors given as a very broad range. Thus point estimate may be poor.
	Fluoride	lb/bu	1.79E-05	4	AP-42 Emission Factor based. Data quality rating excellent.
	Acid Mist	lb/bu	1.01E-03	2	AP-42 Emission Factor based. Data quality rating poor.
	Herbicides	lb/bu	5.06E-03	2	Emission factor rating poor.
	Alachlor	lb/bu	1.01E-03	2	Emission factor rating poor.
	Atrazine	lb/bu	1.86E-03	2	Emission factor rating poor.
	Metolachlor	lb/bu	1.23E-03	2	Emission factor rating poor.
	Cyanazine	lb/bu	9.62E-04	2	Emission factor rating poor.
	Insecticides	lb/bu	8.01E-04	2	Emission factor rating poor.
Water	Fonofos	lb/bu	1.49E-04	2	Emission factor rating poor.
	Turbufofos	lb/bu	3.95E-04	2	Emission factor rating poor.
	Chlorpyrifos	lb/bu	2.57E-04	2	Emission factor rating poor.
	Herbicides	lb/bu	1.97E-04	3	These four herbicides make up 80% of the total herbicide use (out of a total of 26 herbicides) in corn production
	Alachlor	lb/bu	8.82E-06		
	Atrazine	lb/bu	9.55E-05		
	Metolachlor	lb/bu	3.88E-05		

Cyanazine lb/bu	5.36E-05
Insecticides	
Fonofos lb/bu	1.67E-05
Turbufoos lb/bu	2.57E-06
Chlorpyrifos lb/bu	6.81E-06
Chlorpyrifos lb/bu	7.34E-06
Nitrates (as nitrogen)	0.16
Phosphorous	3.92E-03
Potassium	0.02
Resource CoN.G.	
Diesel	28,391
LPG	11,393
Coal	3,210
Oil	522
Gasoline	1,870
Electricity	3,621
Total Fuel	0.494
	49,007
Limestone	1.28
Sulfur	0.436
Water	gallons/bu
Phosphate Rock	lb/bu
Potassium Chloride	lb/bu
Soil	96

- 2 There is little data on insecticide loss
These three insecticides make up 75%
of total insecticide use in corn production.
- 3 Other sources of nitrogen contribute to nitrate loading
- 4 Energy use estimates derived from current data and are consistent with other results.
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- 4 Energy use estimates derived from current data and are consistent with other results.
- 4 Current data but some conflicting estimates.
- 5 Current data.
- 3 Derived from average irrigation practices.
- 5 Current data.
- 5 Current data.
- 3 Total Loss of Soil. See Table 4.

Conversion Factors

Unit from	Unit to	Multiplier	Name	Source:
bu	lb	56	lb_bu	22
Hectares	acre	2.47	acre_hect	22
kg	lb	2.20	lb_kg	22
hectares	sq. meters	10,000	sqmeters_hect	22
meter	feet	3.28	feet_meter	22
short tons	lb	2,000	lb_shortton	22
metric tons	kg	1,000	kg_mton	22
kcal	btu	3.97	btu_kcal	22
Joules	btu	9.47E-04	btu_joule	22
Gallons Etha lb	lb	6.58	lb_gallon	46
Gallons Etha bu	bu	0.4	bu_gallon	12
Hectares	Sq. cm	1.00E+08	sqcm_ha	22
cubic cm	liters	0.001	liters_cm	22
liters	gallons	0.264	gallons_liter	22
sq mile	acres	640	acres_sqmile	22
metric tons	short tons	1.102	shortton_metricton	22
barrels	gallons	42	gallons_barrel	22
kg	grams	1,000	grams_kg	22
cubic foot na bu	bu	1.032	btu_cubict	38
barrel distilla million bu	million bu	5.825	btu_barreloil	38
barrel motor million bu	million bu	5.253	btu_barreigas	38
Short ton coamillon bu	million bu	22.25	btu_toncoal	38
Barrel LPG million bu	million bu	3.614	btu_barrellpg	38
Gallons Waterb	lb	8.337	lb_gallonw	22

Molecular W Element/ConName Wt. Defined Name

H	Hydrogen	1.008
Ca	Calcium	40.08
O	Oxygen	16.00
S	Sulfur	32.06
C	Carbon	12.01
Cl	Chlorine	35.45
K	Potassium	39.10
P	Phosphorus	30.97
N	Nitrogen	14.01
K2O	Potash	94.20
KCl	Muriate of Potash	74.56
CO2	Carbon Dioxide	44.01
CaSO4	Calcium Sulfate	136.14
H2SO4	Sulfuric Acid	98.07
P2O5	Phosphoric Acid	141.94
HNO3	Nitric Acid	63.01
NH4NO3	Ammonium Nitrate	80.04
Ratio CO2:C	carbon_ratio	3.66
Ratio K2O:KCl	Potassium_ratio	1.26
Ratio H2SO4:S	Sulfur_acid	3.06
Ratio S:P2O5	sulfur_Pratio	0.23
Ratio 2N:NH4NO3	N_ammonitrate	0.35
Ratio HNO3:NH4NO3	Ammonia_ratio	0.79
Ratio N:NH3		0.82
Ratio H2SO4:P2O5		0.69

Calculations

Table 1 Corn Yield per Acre Planted (k acres and bushels/acre)

United States Department of Agriculture
National Agricultural Statistics Service
Crop Production: 1994 Summary
Cr Pr 2-1(95)
January 1995

Area in thousands of acres

LCI component

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	10 - Year Average	Year Average
Area Planted	83,398	76,580	66,200	67,717	72,322	74,166	75,957	79,311	73,235	79,158	74,804	75,692
Area Harvest	75,209	68,907	59,505	58,250	64,783	66,952	68,822	72,077	62,921	72,917	67,034	68,079
Area Harvest	7,155	6,418	5,994	8,301	6,606	6,123	6,140	6,069	6,831	5,563	6,520	6,222
Total Area H	82,364	75,325	65,499	66,551	71,389	73,075	74,962	78,146	69,752	78,480	73,554	74,301
Fraction of A	98.76%	98.36%	98.94%	98.28%	98.71%	98.53%	98.69%	98.53%	95.24%	99.14%	98.32%	98.14%
Yield (Corn to	118	119.40	119.80	84.6	116.30	118.5	108.6	131.5	100.7	138.60	115.6	119.0
Adjusted Yield	116.5	117.4	118.5	83.1	114.8	116.8	107.2	129.6	95.9	137.4	113.7	117.5

Notes: Data in bolded rows are from the USDA publication. Since energy is invested in all planted acreage, corn yields are adjusted to the yield per planted acre by multiplying by the fraction of planted acres harvested in any given year. The average yield has been increasing over time. In order to most accurately describe current yields, average yields over the past 20 years can be fit with a simple linear model. The data are converted to a base year of 1975, so that year 1 represents 1975, and year 20 represent 1994. Based on this model (presente 120.54 bu/acre.
This value is stored in the variable yield, and is used throughout this spreadsheet.

Model	R squared = .3859	F test
Intercept	89	0.0001
Year (1 - 20)	1.68	0.0035

Predicted YieQuantity	Units	Adjusted Yield (to account for fraction of planted acreage that is harvested)
1992	119.2 Bu/acre	117.2
1993	120.9 Bu/acre	118.9

1994 122.6 Bulacre 120.5

Table 2 Chemical Usage in Corn Production

(1)
Agricultural Chemical Usage: (Year) Field Crop Summary
United States Department of Agriculture, National Agricultural Statistics Service
Ag Ch 1 (yr)

LCI component	Year	Raw/ Input Quan.				DQI	Transformed Quan.				Raw Average	Transformed Average
		1991 (MM lbs)	1992 (MM lbs)	1993 (MM lbs)	1994 (MM lbs)		1991 (lbs/acre)	1992 (lbs/acre)	1993 (lbs/acre)	1994 (lbs/acre)		
Fertilizers	Raw/Input Units											
	Nitrogen	8,447	8,902	7,956	7,856	10	123	125	121	126	8,290	123.7
	Phosphate	3,331	3,344	2,995	2,992	10	49	47	46	48	3,166	47.2
	Potash	3,910	3,950	3,519	3,603	10	57	55	54	58	3,746	55.9
	(thousand lbs(thousand lbs) (thousand lbs(thousand lbs)											
	(lbs/acre) (lbs/acre) (lbs/acre) (lbs/acre)											
	(lbs/acre) (lbs/acre) (lbs/acre) (lbs/acre)											
Herbicides	2,4-D	2,800	2,832	3,586	3,631	10	0.041	0.040	0.055	0.058	3,212	0.048
	Acetochlor				7,447	10	0.000	0.000	0.000	0.119	1,862	0.030
	Alachlor	37,174	40,129	32,078	21,325	10	0.542	0.562	0.488	0.341	32,677	0.483
	Amefryn	59	146			10	0.001	0.002	0.000	0.000	51	0.001
	Atrazine	52,060	54,939	49,553	45,412	10	0.759	0.769	0.754	0.727	50,491	0.752
	Bentazon	478	550	497	584	10	0.007	0.008	0.008	0.009	527	0.008
	Bromoxynil	1,344	1,389	1,364	1,446	10	0.020	0.019	0.021	0.023	1,386	0.021
	Butylate	8,478	8,117	5,441	2,117	10	0.124	0.114	0.083	0.034	6,038	0.088
	Cyanazine	23,161	26,691	26,453	27,689	10	0.338	0.374	0.403	0.443	25,999	0.389
	Dicamba	3,556	5,068	4,598	6,322	10	0.052	0.071	0.070	0.101	4,886	0.073
	Dimethenamid				2,241	10	0.000	0.000	0.000	0.036	560	0.009
	EPTC	14,355	10,594	11,098	6,124	10	0.209	0.148	0.169	0.098	10,543	0.156
	Flumetsulam				52	10	0.000	0.000	0.000	0.001	13	0.000
	Glyphosate	1,156	746	1,973	1,776	10	0.017	0.010	0.030	0.028	1,413	0.021
	Imazethapyr			11	37	10	0.000	0.000	0.000	0.001	12	0.000
	Linuraon	93	96			10	0.001	0.001	0.000	0.000	47	0.001
	Metolachlor	38,792	41,327	39,026	39,213	10	0.565	0.579	0.594	0.627	39,590	0.591
	Metribuzin			46	41	10	0.000	0.000	0.001	0.001	22	0.000
	Nicosulfuron	75	140	165	249	10	0.001	0.002	0.003	0.004	157	0.002
	Paraquat	201	423	630	400	10	0.003	0.006	0.010	0.006	414	0.006
Pendimetalin	2,745	3,091	2,825	1,806	10	0.040	0.043	0.043	0.029	2,617	0.039	
Primisulfuron	29	30	40	47	10	0.000	0.000	0.001	0.001	37	0.001	
Propachlor	1,456	1,506	1,260	1,184	10	0.021	0.021	0.019	0.019	1,352	0.020	
Simazine	1,081	1,147	1,118	972	10	0.016	0.016	0.017	0.016	1,080	0.016	
Tridiphane	264	123		66	10	0.004	0.002	0.000	0.001	113	0.002	
Trifluralin	111		114		10	0.002	0.000	0.002	0.000	56	0.001	
Total Herbicide	189,468	199,084	181,876	170,181		2.76	2.79	2.77	2.72	185,152	2.760	
(thousand lbs(thousand lbs) (thousand lbs(thousand lbs)												
Insecticides												
	(lbs/acre) (lbs/acre) (lbs/acre) (lbs/acre)											
	Bifenthrin	14	4			10	0.0002	0.0001	0.0000	0.0000	5	0.0001
	Bacillus thur.	2,094			326	10	0.0305	0.0000	0.0000	0.0052	605	0.0089
	Carbofuran	2,278	1,648	1,133	326	10	0.0332	0.0231	0.0172	0.0052	1,346	0.0197
	Chlorpyrifos	6,716	6,247	5,584	5,206	10	0.0979	0.0875	0.0850	0.0833	5,938	0.0884
	Diazinon	116	74			10	0.0017	0.0010	0.0000	0.0000	48	0.0007
Dimethoate	78	74			10	0.0011	0.0010	0.0000	0.0000	38	0.0005	

Erosion By State and Type (1)

Units	Raw/			Transformed			Erosion per Bushel (tons/bu)	Erosion per Bushel (lb/bu)	
	Input Quan. (tons/acre/yr)	Input Quan. tons/acre/yr	Raw/ Input Quan. (tons/acre/yr)	Quan.	Quan.	Quan.			
(million bushels)									
State	Sheet/Rill Erosion	Wind Erosion	Total Erosion	1994 Production	Cumulative	Cum. Fraction	Sheet/Rill Ero	Wind Erosion	Total Erosion
Iowa	5.6	1.4	7	1,930,400	1,930,400	19.11%	10,810,240	2,702,560	13,512,800
Illinois	4.4	0	4.4	1,786,200	3,716,600	36.79%	7,859,280	0	7,859,280
Nebraska	3.6	1.7	5.3	1,153,700	4,870,300	48.21%	4,153,320	1,961,290	6,114,610
Minnesota	2.4	6.3	8.7	915,900	5,786,200	57.27%	2,198,160	5,770,170	7,968,330
Indiana	3.4	0.4	3.8	858,240	6,644,440	65.77%	2,918,016	343,296	3,261,312
Ohio	3.3	0.1	3.4	486,500	7,130,940	70.58%	1,605,450	48,650	1,654,100
Wisconsin	4.1	0.3	4.4	437,100	7,568,040	74.91%	1,792,110	131,130	1,923,240
South Dakota	2.3	2.7	5	367,200	7,935,240	78.54%	844,560	991,440	1,836,000
Kansas	2.3	2.1	4.4	304,590	8,239,830	81.56%	700,557	639,639	1,340,196
Total	31.4	15	46.4	10,103,000			32,881,693	12,588,175	45,469,868
Average	3.49	1.67	5.16				3.25	1.25	4.50
							54.00	20.67	74.68

Erosion by C	Raw/			Raw/		
	Input Quan.	Raw/ Input Quan.	Raw/ Input Quan.	Input Quan.	Raw/ Input Quan.	Raw/ Input Quan.
Sheet/Rill Erosion						
Wind Erosion						
Units						
Land Planted	4.4	1.3	5.7 tons/acre/year			
Highly Erodib	11.2	2.2	13.4 tons/acre/year			
Not Highly Er	2.5	1.1	3.6 tons/acre/year			
All Corn Land	4.3	1.5	5.8 tons/acre/year			
Highly Erodib	10.8	2.3	13.1 tons/acre/year			
Not Highly Er	2.5	1.2	3.7 tons/acre/year			
All Corn Land	71.35	24.89	96.23 lb/bu			

Notes: Bob Kellogg provided this disaggregated data. Soil loss cannot be treated simply as a resource cost, since soil is naturally regenerated over time. This is usually quantified as the soil loss tolerance, usually somewhere between 4 and 5 tons/acre/year. The corn land soil loss estimate used here is slightly above this value, indicating that some degradation of corn cropland is occurring. Soil losses have been decreasing steadily in the past decade, however, indicating that average losses will soon be in the soil loss tolerance range.

Table 5 Water Use in Irrigation

(1)	United States Department of Agriculture. 1994 (revised 1995). Summary Report: 1992 National Resources Inventory, USDA Natural Resources Conservation Service and the Iowa State University Statistical Laboratory.
(2)	Ali, Mir, and W. McBride. 1994. Corn: State-Level Production Costs, Characteristics, and Input Use, 1991, USDA/ERS, SB-891.
(3)	United States Department of Agriculture. National Agricultural Statistics Service, Crop Production: 1994 Summary, Cr Pr 2-1(95), January 1995.
(4)	Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

Weighting Data					
Input Quan. (acres)		Input Quan. (acres)		Input Quan. (acres)	
Raw/	Raw/	Raw/	Raw/	Raw/	Raw/
Input Quan. (acres)	Input Quan. (acres)	Input Quan. (acres)	Input Quan. (acres)	Input Quan. (acres)	Input Quan. (acres)
1994 Production (3)	Cumulative	Cum. Fraction	Irrigated	Non-Irrigated	Total
Percentage	Percentage	Percentage	Percentage	Percentage	Percentage
Requirements (4) (cm)	Weighted by % irrigated	Times Production			

(8) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

(9) Kirk-Othmer. 1982. The Encyclopedia of Chemical Technologies, Vol. 10, "Fertilizers".

Energy Requirements for Fertilizer Production (GJ/metric ton fertilizer)

	Natural Gas	Electricity	Oil	Steam	Exported Steam	Total
Anhydrous A	40.79	1.1	0	0	0.38	41.51
Urea	26.02	2.55	0	3.7	0.81	31.46
Nitrogen Solu	16.11	1.02	0	0.63	0.37	17.39
Triple Superp	0.54	2.51	0.55	1.89	2.35	3.14
Potash (as K)	2.69	2.11	0	0	0	4.8

Notes: Taken from Table 16 of reference 4 (p. 26).

Energy Requirements for Fertilizer Production (Btu/lb except electricity, which is kwh/lb)

	Natural Gas	Electricity	Oil	Steam	Exported Steam	Total (Btu/lb)	Total (kwh/lb)
Anhydrous A	17,523	0.047	0	0	163	17,360	0.047
Urea	11,178	0.110	0	1,590	348	12,420	0.110
Nitrogen Solu	6,921	0.044	0	271	159	7,033	0.044
Triple Superp	232	0.108	236	812	1,010	271	0.108
Potash (as K)	1,156	0.091	0	0	0	1,156	0.091

Notes: Reference 7 gives the original survey data, and says that electricity is converted to btu using the convention of 10,000 btu/kwh (i.e. accounting for losses). I have converted back to kwh.

Nutrient Content of Fertilizers

	Source:
Anhydrous A	82% Nitrogen
Urea	46% Nitrogen
Nitrogen Solu	30% Nitrogen
Triple Superp	46% P2O5
Potash (as K)	100% K2O

Notes: Reference 4 uses these nutrient contents. Reference 3 uses 44 to 46% for triple superphosphate, and 28 to 32% for nitrogen solutions. We follow the convention of reference 4.

Energy Requirements for Fertilizer Production (Btu/lb nutrient)

	Natural Gas	Electricity	Oil	Steam	Exported Steam	Fuel Total	Electricity Total	Total (Btu/lb)
Anhydrous A	21,370	0.058	0	0	199	21,171	0.058	576
Urea	24,300	0.238	0	3,455	756	26,999	0.238	2,381
Nitrogen Solu	23,069	0.146	0	902	530	23,442	0.146	1,461
Triple Superp	504	0.234	514	1,765	2,195	588	0.234	2,344
Potash (as K)	1,156	0.091	0	0	0	1,156	0.091	906

Notes: Reference 8 cites the Fertilizer Institute for energy consumption estimates of 22,159 Btu/lb nitrogen, 4,175 Btu/lb P2O5, and 1,245 Btu/lb potash. The nitrogen estimate is close to what reference 4 gets here, but differs significantly for the other fertilizers. Examination of reference 7 reveals that the estimate for potash seems to come from a 1985 survey by the Fertilizer Institute. The value given is 2,489 kbtu/ton potash. This converts to 1,245 Btu/lb of potash. Reference 4 uses this data, plus fuel breakouts from a 1979 survey, but then converts to K2O assuming that the energy use value is for muriate of potash, and that muriate of potash is 60% K2O. This yields our value of 2,065 Btu/lb K2O. Since most references cite potash consumption for agricultural uses in terms of weight of K2O, it is not clear whether reference 8 has used an appropriate energy intensity figure.

Estimating energy use in phosphate production is confused by the fact that sulfuric acid production is highly exothermic. If all of this energy is counted towards phosphoric acid production, in some cases the total energy use is still negative. The estimates given in reference 7, and used by reference 4 seem to exclude energy use in sulfur mining. Reference 3 however, includes energy use in sulfur mining, and cites a total energy consumption

of 7,200 btu/lb P2O5 for triple superphosphate. Reference 9 also gives a fairly high figure of 5,500 btu/lb P2O5 for triple superphosphate. Some estimates are given below.

Energy Intensity of Phosphate Fertilizer Production

Raw Input Q/Units	Source	Transformed Input Units	Electricity	Natural Gas	Oil	Units
7,200 Btu/lb P2O5	(3)	7,200 Btu/lb K2O5				
2,300 kcal/kg P2O5	(1)	4,140 Btu/lb K2O5				
12.79 GJ/ton P2O5	(9)	5,495 Btu/lb K2O5				
4,175 Btu/lb P2O5	(8)	4,175 Btu/lb K2O5	1,962	1,086		1,127 Btu/lb
			0.196			kwh/lb

Notes: Reference 3 is very high, however Fertilizer Institute surveys suggest that the energy use for P2O5 production dropped in half from the 1979 to the 1983 survey (as cited in reference 4) suggesting that modern production processes would be in line with other estimates. Lacking a better method I will use the value cited in reference 8, from the Fertilizer Institute, and assume that this is the best representation of average U.S. practices.

Energy Requirements for Fertilizer Production (Btu/lb nutrient)

	Natural Gas	Electricity (KwDil)	Total Fuel	Total (kwh at Natural Gas	Fuel Oil	Fraction of Fuels
Anhydrous A	21,171	0.058	0	21,171	21,747	100%
Urea	26,999	0.238	0	26,999	29,381	100%
Nitrogen Solu	23,442	0.146	0	23,442	24,902	100%
Phosphates	1,086	0.196	1,127	2,213	4,175	49%
Potash	1,156	0.091	0	1,156	2,062	100%

Table 8 Energy Use for Fertilizer Packaging and Transportation

- (1) Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangilo. 1993. Energy Use in Synthetic Agricultural Inputs: Revised. Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-98732/2.
- (2) Mudahar, M.S. and T.P. Hignett. 1981. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.
- (3) Mudahar, M.S. and T.P. Hignett. 1982. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

Energy Use for Packaging and Transportation

	Nitrogen	Phosphorous	Potash	Units
Packaging	2.58	2.65	1.75	GJ/mt
Transportatio	4.47	5.68	4.60	GJ/mt
Total	7.05	8.33	6.35	GJ/mt

	Nitrogen	Phosphorous	Potash	Units
Packaging	1,108	1,138	752	Btu/lb
Transportatio	1,920	2,440	1,976	Btu/lb
Total	3,029	3,579	2,728	Btu/lb

Notes: This data is used by reference 1 to estimate packaging and transportation energy use for fertilizers. Reviewing the source, however, this data was generated with particular reference to international applications, and thus may not be representative of U.S. average practices, especially for transportation. By comparison, the energy needed to make packaging material is quite small (see below). Also, most fertilizer is shipped in bulk in the U.S. (also below). Anhydrous ammonia, which is the most important form of nitrogen use for corn in Iowa, is also the least energy intensive to transport (pipeline). Thus it will be assumed that the energy use to package fertilizers for corn use is negligible. Transportation energy use estimates are included in the estimates of direct energy use on the farm, and are derived from Shapouri et al 1995.

Energy Use for 50 Kg Polyethylene Plastic Fertilizer Bags (3)
420 MJ/metric ton 180 Btu/lb

Consumption of Fertilizer by Class in the U.S. 1992

Short tons		
Dry Bulk Sing	12,313,103	94% of single nutrient is bulk
Dry Bagged S	742,949	6%
Total Dry Sin	13,056,052	
Dry Bulk Mul	10,949,818	78% of multinutrient is bulk
Dry Bagged M	3,126,493	22%
Total Dry Mu	14,076,310	
Total Fluid	18,085,682	40% of total is liquid
Total	45,218,045	

Table 9 Energy Use in the Production of Herbicides and Insecticides

- (1) Bhat, Mahadev G., Burton C. English, Anthony Turfallow, and Herzron Nyangilo. 1994. Energy Use in Synthetic Agricultural Inputs: Revisited, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.
- (2) Pimentel, David et al. 1988. Food Versus Biomass Fuel: Socioeconomic and Environmental Impacts in the United States, Brazil, India, and Kenya, Advances in Food Research, Vol. 32, pp. 185-238, 1988.
- (3) Weinblatt, Herbert, T.S. Reddy, and Anthony Turfallow. 1982. Energy and Precious Fuels Requirements of Fuel Alcohol Production, Vol. II, Appendices A and B: Ethanol from Grain, DOE/INSAI0292-1
- (4) Green, M.B. 1987. Energy in Pesticide Manufacture, Distribution and Use, in Energy in World Agriculture, Energy in Plant Nutrition and Pest Control, Volume 2, Z.R. Helsel (ed.), Elsevier Press, New York.

Energy Intensity of Pesticide Production (per unit a.i.) (4 and 1)

Herbicide	Energy Intensity (GJ/lor)	Energy Inten Use Rate (lb/bu)	Energy Int. x Use Rate	
2,4-D	85	36,516	4.01E-04	14.63
Alachlor	278	119,428	4.01E-03	478.89
Atrazine	190	81,623	6.24E-03	509.42
Bentazon	434	186,445	6.55E-05	12.21
Bromoxynil	150	64,440	1.72E-04	11.09
Butylate	141	60,573	7.34E-04	44.47
Chlorosulfuron	365	156,803		0.00
Cyanazine	201	86,349	3.23E-03	278.86
Dicamba	295	126,731	6.10E-04	77.26
Diuron	270	115,991		0.00
EPTC	160	68,736	1.30E-03	89.03
Fluazifop-me	518	222,531		0.00
Glyphosate	454	195,037	1.78E-04	34.69
Isopropalin	150	64,440		0.00
Linuron	290	124,583	5.60E-06	0.70
MCPA	130	55,848		0.00
Methazole	150	64,440		0.00
Metolachlor	276	118,569	4.91E-03	581.76
Metribuzin	200	85,919		0.00
Molinate	150	64,440		0.00
Norflurazon	150	64,440		0.00
Pendimethali	150	64,440	3.22E-04	20.74
Prometryn	200	85,919		0.00
Propanil	220	94,511		0.00
Trifluralin	150	64,440	6.95E-06	0.45
Propachlor	290	124,583	1.67E-04	20.78

Paraquat	480	197,615	5.15E-05	10.18
			0.02	2185.16
		Wt. average Energy Intensity		97,575

Notes: Reference 1 cites reference 4 data, then uses the data to extrapolate to pesticides not covered by reference 4. Reference 1 incorrectly cites the energy intensity of diuron at 200 GJ/mt, instead of 270 GJ/mt from the original reference. The other values are correct. Use rates are from Table 2 of this sheet.

Energy Intensity of Insecticide Production (1 and 4)

Insecticide	Energy Intensity (GJ/ton)	Energy Inten Use Rate (lb/ibu)	Energy In. x Use Rate
Chlorpyrifos	250	107,399	7.34E-04
Fenofos	200	85,919	2.57E-04
Fensulfthion	200	85,919	0.00
Terbufos	200	85,919	6.81E-04
Carbofuran	454	195,037	1.63E-04
Methyl parath	160	68,736	8.53E-05
Phorate	209	89,786	1.44E-04
			2.10E+02
Wt. Average			101,742

Other estimates of Energy Use in Pesticide Production

Insecticide	100,000	kcal/kg	(2)	179,999	Btu/lb
Herbicide	100,000	kcal/kg	(2)	179,999	Btu/lb
Pesticides	231,000	Btu/acre	(3)	2,265	Btu/bu
Wisconsin	228,000	Btu/acre	(3)	2,092	Btu/bu
Nebraska	245,000	Btu/acre	(3)	2,333	Btu/bu
Kansas					

Table 10 Energy Use in Pesticide Formulation and Packaging

(1) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(2) Green, M. 1987. Energy in Pesticide Manufacture, Distribution, and Use, Energy in Plant Nutrition and Pest Control, ed. Z.R. Halsei, New York, Elsevier, pp. 165-196.

Pesticide Formulation and Packaging Energy Use

Energy Use		Raw Input/ Quantity	Raw/ Input Units	Source	Transformed Notes:		Fuel Types (%)		
					Input Quan.	Input Units	Oil	Gas	Coal
Herbicides	Miscible Oil	41,800	kcal/kg	(1)	75,240	Btu/lb			17%
	Wettable Powder	5,100	kcal/kg	(1)	9,180	Btu/lb			20%
	Granules	23,600	kcal/kg	(1)	42,480	Btu/lb			21%
	Average	23,500	kcal/kg		42,300	Btu/lb			19%
Insecticides	Miscible Oil	41,800	kcal/kg	(1)	75,240	Btu/lb			16%
	Wettable Powder	5,100	kcal/kg	(1)	9,180	Btu/lb			20%
	Granules	23,600	kcal/kg	(1)	42,480	Btu/lb			21%
	Dust	23,600	kcal/kg	(1)	42,480	Btu/lb			21%
	Average	23,525	kcal/kg		42,345	Btu/lb			20%

Pesticides	Miscible Oil	22 GJ/mt	(2)	9,451 Btu/lb
	Wettable Powder	32 GJ/mt	(2)	13,747 Btu/lb
	Granules	12 GJ/mt	(2)	5,155 Btu/lb
	Average	22 GJ/mt	(2)	9,451 Btu/lb

Notes: There is extremely wide variation in pesticide energy intensity estimates. Though pesticide use in corn farming is small on a mass basis, because pesticides are very energy intensive, the overall impact on corn energy use is not insignificant. Lacking a better reason, reference 2 will be used because it is more recent.

Table 11 Energy Use in Seed Production

(1) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

(2) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(3) Giampietro, M., and David Pimentel. 1990. Alcohol and Biogas Production from Biomass, Critical Reviews in Plant Sciences, Vol. 9, No. 3, pp. 213-233.

(4) Economic Report to the President. 1995. Transmitted to the Congress February 1995, U.S. GPO, Washington, D.C.

(5) United States Department of Energy. Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

(6) Personal Communication with David Bruch, Gro-Mart Seed Division, Bloomington, IL, Sept. 20, 1995.

Seeding Rate	0.12 lb/bu
	0.0021 lb seed/lb corn

Raw/ Input Quan.	Raw/ Input Units	Source	Transformed Input Quan.	Transformed Input Units	Notes:
186 Btu/bu	(1)	186 Btu/bu	186 Btu/bu	9-State Average	
24,806 Kcal/kg seed	(2)	5,285 Btu/bu	5,285 Btu/bu	U.S. Average	

Notes: Sources (2) and (3) rely on estimates of the energy intensity to propagate crops based on the relative cost of feed corn versus hybrid seed corn. Using 1977 data on the retail cost of corn seed (\$0.71/lb) and 1973 energy use per \$GNP (15,800 kcal/\$), the energy cost is computed at 24,806 kcal/kg. This is the approximate figure which is used in both the referenced sources. Reference 1 is based on the assumption that seed requires 150% of the energy that is required for grain. Neither method is particularly appealing. One relies on very gross assumptions about the relationship of costs and energy consumption in the hybrid corn seed industry, the other is just a guess. Lacking other options, it is at least possible to update the estimates based on energy use per unit gross domestic product. This data is presented below.

Year	Domestic Energy (Quads)	Cons/Gross (Billion \$)	Dome Ratio Btu/\$ GDP	Ratio (Kcal/\$ GDP)/(\$80,000 Kernels)	Seed Cost (\$/lb)	Kernels/lb	Seed Cost (\$/lb)	Energy Intensity (Btu/lb seed)	Energy Intensity (Btu/bu corn)
1991	81.12	5724.8	14,170	3,571	70.2	1300	1.14	16,164	1,913
1992	82.14	6020.2	13,644	3,439	71.8	1300	1.17	15,919	1,884
1993	83.96	6343.3	13,236	3,336	72.7	1300	1.18	15,637	1,851
Average			13,683						1,883

Notes: Accordingly, the current estimate of energy use to produce corn seed is much smaller than the estimate made based on 1970's data. This is due both to a more energy efficient economy (i.e. lower bu/\$ GDP) and due to lower seed prices (current prices are equivalent to about \$0.45/lb in 1977 dollars). Interestingly, my estimate of the energy intensity of the U.S. economy in 1973 is also about 12% less than the estimate made in reference 2. Combined, current energy intensity estimates are only about 40% of those made based on the 1970's data. The veracity of the gross argument made is also still in question. As a rough check, however, it is interesting to estimate the energy intensity of corn production based on the same method. Ass 34,208 Btu/bu. This is 63.41% of the estimate made in this report. Thus the seed energy intensity estimate can be considered a valid, but crude, estimate.

As a check, a rough direct estimate can be made of the energy use to grow seed. David Bruch cited some 1994 production numbers of 47 units net production per acre, and planting rates of about 27,000 plants per acre. This works out to 3 acres seeded per unit, or:

47 units seed/acre seed
3 acres grain/unit seed
141 acres grain/acre seed

Energy use p 6,503,299 Btu/acre corn

Assuming equivalent energy use per
acre seed, energy use per acre grain for
seed is: 46,123 Btu/acre corn
or: 383 Btu/bu corn

This is already double the estimate in reference 1, and does not include any additional energy for seed processing. There are many aspects of seed production which are markedly more energy intensive than grain. For example, seed corn is planted in two passes, one for each of the parents. An additional tractor pass is made to burn back one or two rows to ensure proper pollination. In some cases pesticide use is very much higher. This year, for example, some fields were sprayed up to 4 times from corn borer. Seed corn is also mechanically dehusked. Probably the most significant area of additional energy use, however, is in drying and storage. Seed corn is harvested wet (35% moisture) and dried on the ear down to 12% moisture. Using data from Table 17 an estimate of drying energy use can be made:

Harvested moisture of c	35%
Stored moisture of corn	12%
Harvested water weight	26.54 lb/bu
Stored water weight	6.72 lb/bu
Stored corn weight	49.28 lb/bu
Water to be evaporated	19.82 lb/bu

Gross Energy to Dry Se	35,691	btu/bu seed
Gross Energy to Dry Se	637	btu/lb seed
Energy per unit corn pro	75.43	btu/bu corn

This does not include the water in the cob itself, so energy use for drying would be even higher. Clearly different practices in the seed industry lead to dramatically higher energy costs. The calculation below is a rough estimate of incremental additions in energy use on the farm for hybrid seed production. Included are estimates of triple the farm machinery use, 20% additional energy for drying due to water in the cob, and double the energy use for pesticides.

Item	Energy use per Acre	Estimated M/Energy Use per A/Energy Use per Bu corn
Nitrogen	2,876,833	1 2,876,833 55,700 118
Polash	115,234	1 115,234 2,231 5
Phosphate	197,113	1 197,113 3,816 8
Lime	90,198	1 90,198 1,746 4
Chemicals	325,118	2 650,236 12,590 27
Drying	1,606,101	1.2 1,927,322 37,316 79
Farm Vehicle	1,644,030	3 4,932,089 95,494 202
Total	6,854,628	10,789,026 208,894 442

Notes: Assumes 80,000 kernels/unit and 1,300 kernels/lb. Some additional energy is used for airconditioned storage of seed, packaging, and transportation, but it seems unlikely that this would increase the total as high as the value estimated from btu/\$ GDP. The actual value is probably between 600 and 1800 btu/bu corn. Lacking more detailed data on corn seed production practices, however, the estimate based on btu/\$ will be used.

Table 12 Energy Use in Lime and Sulfur Production

(1) Hudson, Charles L. 1982. Energy Requirements for Materials Used in Vehicles Characterized for the Tapcut Project, Argonne National Laboratory, ANL/EES-TM-211.

(2) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(3) Giampietro, M., and David Pimentel. 1990. Alcohol and Biogas Production from Biomass, Critical Reviews in Plant Sciences, Vol. 9, No. 3, pp. 213-233.

(4) Blankenhorn, Paul R., et al. 1986. Net Financial and Energy Analyses for Producing Populus Hybrid Under Four Management Strategies: First Rotation, Oak Ridge Nat'l Laboratory, ORNL/Sub/79-07928/1.

(5) Mudahar, M.S. and T.P. Hignett. 1982. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

(6) U.S. Department of the Interior, Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

Energy Use in Lime and Sulfur Production

Lime	316 kcal/kg	(3)	569 Btu/lb
	566 Btu/lb	(4)	566 Btu/lb
	315.45 kcal/kg	(2)	568 Btu/lb
		Average	568 Btu/lb
		St. Dev.	1 Btu/lb

This source explicitly states that 300 kcal/kg is transport.

Notes: I suspect that all three of these sources are relying on the 1980 estimate by Pimentel of the energy use to produce limestone.

Pimentel's estimates suggest that almost all of the energy use is for transport of the limestone, while mining costs are very small.

He cites no data source for the transportation estimate, however, making the total value somewhat questionable. Apparently this single value has propagated through the literature for some time. There is no apparent source of better data. The mining part of the energy consumption estimate is based on 1972 Census of Mineral Industries data.

	GJ/mt		
Sulfur	7.38	9,511 Btu/lb	(5)
Percent of Su	21%	1997 Btu/lb	(6)

Notes: About 15% of domestic sulfur use in the U.S. is domestically produced, Frasch Process sulfur. Domestically produced recovered sulfur accounts for 55%. Since sulfur recovery is often carried out in the purification of fuel feedstocks, or for pollution control purposes, it is unclear whether energy use in these processes should be counted towards sulfur production. Hudson (1) cites an energy intensity of sulfur production of 443 Btu/lb.

Table 13 Fertilizer Type Mix in Iowa (a state heavily devoted to corn production)

(1) Tennessee Valley Authority, Commercial Fertilizers: 1994, TVA Environmental Research Center, TVA, Muscle Shoals, Alabama.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Iowa Fertilizer Consumption : 1994 (1)

	Raw Input Quantity	Units	Notes:	Percent
Nitrogen	103186	short tons N	p. 17	
Multi Nutrient Grade	932724	short tons N	p. 17	
Single Nutrient Grade	1035910	short tons N	p. 17	
Total N				
Phosphates	284130	short tons P2O5	p. 17	
Multi Nutrient Grade	9844	short tons P2O5	p. 17	
Single Nutrient Grade	293974	short tons P2O5	p. 17	
Total P2O5				
Potassium	38507	short tons K2O	p. 17	
Multi Nutrient Grade	403517	short tons K2O	p. 17	
Single Nutrient Grade	442024	short tons K2O	p. 17	
Total K2O				
Single Nutrient Anhydrous Ammonia	597445	short tons N	p. 20	65.08%
Nitrogen Solutions	235127	short tons N	p. 20	25.61%
Urea	85472	short tons N	p. 20	9.31%
Total Single	918044	short tons N		98.43% Of total single nutrient N
Multiple Nutr DAP	378850	short tons DAP	p. 15	

68193	short tons N	p. 15	66.09% Of total multi nutrient N
174271	short tons P2O5	p. 15	59.28% Of total P2O5
30923	short tons K2O	p. 21	90.70% Of total K2O

Potassium	Potassium Chloride	400.923	short tons K2O	p. 21	90.70% Of total K2O

Notes: Fertilizer use in Iowa is weighted towards single nutrient types except for phosphates, for which DAP is the most common type used. In order to simplify the evaluation of energy and emissions associated with fertilizer manufacture, nitrogen energy intensity will be estimated from the weighted average of the single nutrient nitrogen sources, and phosphate energy intensity will be taken from a generic value for phosphate fertilizers. Emissions estimates will then be derived from the quantity of raw materials and intermediates used to manufacture the fertilizers.

Physical and Chemical Characteristics of Nitrogen Solution (2)
(28% N in solution)

Urea N: Amm	1.04 (unitless)
Urea N	50.98%
Ammonium N	49.02%

Table 14 Corn Production Energy Use for Fertilizer

Fertilizer Energy Intensity in Corn Production		Fuel Energy Intensity				Electric Intensity				Notes	
	Quantity (lb/bu)	Fuel (Btu/lb)	Electric (kwh/lb)	Fuel (Btu/bu)	Electric (kwh/bu)	Fuel (Btu/bu)	Electric (kwh/bu)	Fuel (Btu/bu)	Electric (kwh/bu)	Fuel (Btu/bu)	Electric (kwh/bu)
Calculated	N	1.03	22,295	0.097	22,871	0.100	Fraction of Fertilizer type and fraction of makeup of nitrogen solution from T	22,871	0	0.100	Total
	P	0.39	2,213	0.196	867	0.077	Average of fertilizer types	425	442	0.077	1,635
	K	0.46	1,156	0.091	536	0.042	Average value	536	0	0.042	956
	Total	1.88	25,663	0.384	24,273	0.222		23,831	442	0.218	26,458

Notes: Energy use from fertilizer consumption is calculated from the quantity of fertilizer used (Table 2), the energy intensity of fertilizer production (Table 7), and, for nitrogen, some information about the mix of nitrogen fertilizer types used in Iowa (Table 13). Fuel mix information is also in Table 7.

Table 15 Direct Energy Use in Corn Production

(1) Shapouri, H., J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

(2) Ali, Mir, and W. McBride. 1994. Corn: State-Level Production Costs, Characteristics, and Input Use, 1991, USDA/ERS, SB-891.

[illegible]

LP Gas	Btu/bu	3,210
Natural Gas	Btu/bu	2,557
Electricity (2)	Kwh/bu	0.276
Total		19,406

Notes: Electricity use per bushel has been converted back to Kwh using the conversion factor given in reference 1 (12,456 btu/kwh). This value can be checked in reference 2, and is correct. Following the convention in reference 1, energy use for custom work and input hauling has been allocated to the diesel category. Energy use in custom drying is allocated to the LPG and natural gas categories according to the relative importance of these two fuels (44% N.G.: 56% LPG).

Table 16 Dryer Type Specific Energy Intensity Estimates

- (1) Personal Communication with Dr. Charles Hurburgh, Iowa State University, July 24, 1995.
- (2) Personal Communication with Dr. Fred Bakker-Arkema, Michigan State University, Department of Ag. Engineering, July 27, 1995.
- (3) Personal Communication with Bill Wilcke, University of Minnesota, Department of Ag. Engineering, July 25, 1995
- (4) Iowa Agricultural Statistics. 1991. Iowa Crop Report, press release of March 5, 1991, Iowa Agricultural Statistics, Des Moines, Iowa.

Corn Drying Energy Consumption Estimates

Dryer Type	Energy	Units	Source	Notes:
Low Temp.		1,400 Btu/lb water	(1)	He gave these as the range of possible values, in which most dryers should fall.
High Temp.		3,000 Btu/lb water	(1)	
Ambient Air-L		1,450 Btu/lb water	(2)	Range: 1,200 to 1,600
High Temp. B		1,950 Btu/lb water	(2)	Range: 1,500 to 2,400
Continuous High Temp.				
Cross Flow		2,050 Btu/lb water	(2)	Range: 1,700 to 2,400
Mixed Flow		1,800 Btu/lb water	(2)	Range: 1,600 to 2,000
Concurrent F		1,650 Btu/lb water	(2)	Range: 1,500 to 1,800
Average		1,833 Btu/lb water		
Bin Batch		1,500 Btu/lb water	(3)	Range: 2,100 to 3,200
Column Batch		2,100 Btu/lb water	(3)	
Continuous F		2,650 Btu/lb water	(3)	
Natural w/e		1 kwh/bu	(3)	From 22 to 15% moisture
		870 Btu/lb water		

Percent of Corn Dried By Type: Iowa 1990 (4)

Energy Inten Product	
Column Type	9.1%
Column Type	13.6%
Batch-in-Bin	21.4%
Continuous-f	17.5%
Bin Dryer wit	35.9%
Other	2.5%

Mid-Range Energy Intensity Estimate
1,801 Btu/lb water

Table 17 Net Corn Drying Energy Intensity

- (1) Iowa Agricultural Statistics. 1991. Iowa Crop Report, press release of March 5, 1991, Iowa Agricultural Statistics, Des Moines, Iowa.
- (2) Hill, L.D., J.P. Brophy, S. Zhang, and W. Florkowski. 1991. Farmer Attitudes Towards Technological Changes Affecting Grain Handling and Quality. Bulletin 805, University of Illinois at Urbana-Champaign, College of Agriculture, Agricultural Experiment Station.
- (3) CE Power Systems. 1967. Steam Tables: Properties of Saturated and Superheated Steam, reprinted from ASME Steam Tables (1967).
- (4) Cengel, Y. A., and M. Boles. 1989. Thermodynamics: An Engineering Approach, McGraw-Hill, Inc., New York.
- (5) Personal communication with Bill Wilcke, University of Minnesota, Department of Agricultural Engineering, July 25, 1995.
- (6) Personal communication with Fred Bakker-Arkema, Michigan State University, July 27, 1995.
- (7) Shapouri, H., J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.
- (8) Ali, Mir, and W. McBride. 1994. Corn: State-Level Production Costs, Characteristics, and Input Use, 1991, USDA/ERS, SB-891.

Source:
Corn Dried by Method: Percent of To(1)

Year	1986	1988	1989	1990	Average
Natural Dryin	15.3	20.7	22.8	19	19.45
On Farm Ari	68.1	61.5	58.1	62.1	62.45
Off Farm Ari	16.6	17.8	19.1	18.9	18.10%

Source:
Percent of Cq(2)

	1971	1976	1986	1991
Illinois	34	42	49	38
Iowa	27	45	53	47
Indiana	36	53	58	31
Average	32	47	53	39

Notes: Information on corn drying varies significantly from source to source. The above information includes some of the available estimates of the fraction of corn dried, and the fraction dried on and off of the farm. Because of conflicting estimates, estimates of fuel use for corn drying were taken directly from reference 7. This are compared below to theoretical values.

Item	Value	Units	Source	Notes:
Specific Heat of Water	1	btu/lb-degree Ra	(4)	
Enthalpy of vaporization	970.30	btu/lb	(3)	At 1 atmosphere
Energy to vaporize water from 70 F	1112.30	btu/lb	(3)	
Harvested moisture of corn	23%		(5)	
Stored moisture of corn	15%		(5)	
Harvested water weight	14.22	lb/bu		
Stored water weight	8.40	lb/bu		
Stored corn weight	47.60	lb/bu		
Water to be evaporated	5.82	lb/bu		
Gross Energy to Dry Corn	10,480	lb/bu		
Net Energy to Dry Corn	5,764	lb/bu		

Notes: Assuming an average of 55% of corn is dried, net energy use values correspond to estimates in reference 7 for corn dried from 23% to 15%, or 8% points. This estimate is not inconsistent with rough estimates

given by Bill Wicke (10%) and Fred Bakker-Arkema (5% to 12%). Because more accurate data are lacking, it will be assumed that the energy intensity value derived in reference 7 is the most appropriate. Thus all energy use for drying is accounted for in Table 15.

Table 18 Net On-Farm Energy Use

From Table 15				Energy Use for Corn, 9-State Weight		Raw/ Input Units		Source		Transformed Input Units		Notes	
				Raw/ Input Quan.	Raw/ Input Units								
Diesel				10,146	Btu/bushel			Table 15		10,146	Btu/bu		Based on 9 state average.
Gasoline				3,493	Btu/bushel			Table 15		3,493	Btu/bu		Based on 9 state average.
L.P.G.				3,210	Btu/bushel			Table 15		3,210	Btu/bu		Based on 9 state average.
Natural Gas				2,557	Btu/bushel			Table 15		2,557	Btu/bu		Based on 9 state average.
Electricity				3,438	Btu/bushel			Table 15		0,276	Kwh/bu		Based on 9 state average.
Total				22,166	Btu/bushel								

Table 19 Energy Use for Fertilizer in Corn Production

Calculated Values from the last rows of Table 14

Energy Use for Fertilizer Production		Raw/Input Quantity		Units		Source		DQI		Notes:	
Electricity				0.218	Kwh/bushel		Table 14			7	
Fuel Oil				442	Btu/bushel		Table 14			7	
N.G.				23,831	Btu/bushel		Table 14			7	
Total				26,458	Btu/bushel		Table 14			7	

Table 20 Energy Use for Pesticide Use in Corn Production

From Tables 9 and 10.

Pesticide ProQuantity Units (lb/bu)		Energy Inten (Btu/lb)		Energy Use (Btu/bu)		Oil (Btu)		Gas (Btu)		Coal (Btu)	
Herbicides		0.023	97,575	2,234	1,080			722		432	
Insecticides		0.0022	101,742	225	106			76		44	
Pesticide ForQuantity and Packagirt(lb/bu)											
Herbicides		0.023	9,451	216	105			70		42	
Insecticides		0.0022	9,451	21	10			7		4	
Total Pesticide Energy Use											
Oil		1,300	Btu/bu								
N.G.		875	Btu/bu								
Coal		522	Btu/bu								
Total		2,697	Btu/bu								

Notes: Energy intensity for production from Table 9, reference 1. Energy intensity for formulation and packaging from Table 10, reference 2. Fuel mix for total energy use from Table 10, reference 1.

Table 21 Energy Use for Seed in Corn Production

(1) Shapouri, H., J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

Fuel	% fuel	Energy	Units
Gasoline	6.80%	128	Btu/bu
N.G.	59.90%	1,128	Btu/bu
Diesel	26.50%	499	Btu/bu
Oil	6.80%	128	Btu/bu
Seed Produc	100.00%	1,883	Btu/bu

Notes: Energy type splits from reference 1, in percent, applied to total energy for seed production from Table 11.

Table 22 Energy Use for Lime and Sulfur in Corn Production

From Table 6

Lime	728	btu/bu
Sulfur	20.39	btu/bu
Total	748	btu/bu

Energy Split	
Diesel	748

Note: Reference (1) gives an energy type distribution for lime that includes mostly natural gas and coal. Reference (2) suggests that 95% of fuel use in limestone production is for transportation. Since reference (2) is more explicit about the processes uses, it is assumed that 300 kcal/kg of energy use is for truck haulage, and that diesel trucks are used for this haulage. The remaining energy consumption, and the consumption of energy for sulfur, are lumped into the diesel category because they are small contributions, and there is little data about the mix of fuels for these categories.

Table 23 Total Energy Use in Corn Production

Sum of Previ Total	Units	Table 12 Pesticide	Table 13 Produce Direct Use	Table 14 Fertilizer ProdSeed	Table 15 ProduceLimestone/Sulfur	Table 16
N.G.	28,391	Btu/bushel	875	2,557	23,831	1,128
Diesel	11,393	Btu/bushel	0	10,146	0	499
LPG	3,210	Btu/bushel	0	3,210	0	0
Coal	522	Btu/bushel	522	0	0	0
Oil	1,870	Btu/bushel	1,300	0	442	128
Gasoline	3,621	Btu/bushel	0	3,493	0	128
Electricity	0.494	Kwh/bushel	0.000	0.276	0.218	0.000
Total Fuel	49,007	Btu/bushel	2,697	19,406	24,273	1,883
Total Electric	0.494	Kwh/bushel	0.000	0.276	0.218	0.000
Grand Total	53,952	Btu/bushel	2,697	22,166	26,458	1,883

Table 24 Nitrogen Oxide Emissions from Corn Production

(1) Eichner, Melissa. 1990. Nitrous Oxide Emissions from Fertilized Soils: Summary of Available Data, J. of Environmental Quality, 19:272-280(1990)

(2) Anderson, I.C., and J. S. Levine. 1987. Simultaneous Field Measurements of Biogenic Emissions of Nitric Oxide and Nitrous Oxide,

Journal of Geophysical Research, vol. 92, no. D1, pp. 965-976, January, 1987.

- (3) DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

- (4) Unnasch, Stefan. 1990. Greenhouse Gas Emission from Ethanol Production and Vehicle Use, Acurex Corp. for the Nat'l Corn Growers Association

- (5) Watson, R.T. et al. 1990. Greenhouse Gases and Aerosols, in Intergovernmental Panel on Climate Change, Climate Change: The IPCC Scientific Assessment Report Prepared by Working Group I, J.T. Houghton, et al (ed.), UK, 1990.

LCI Component

N2O Emissions	Raw Input Quantity	Units	Source	Transformed Input Quantity	Units	Notes
	0.01 percent	(4)		1.03E-04 lb/bu		Refs 4 and 5 probably are citing the same data, though they reference different sources.
	2 percent	(4)		2.05E-02 lb/bu		
	0.01 percent	(5)		1.03E-04 lb/bu		Refs 4 and 5 probably are citing the same data, though they reference different sources.
	2 percent	(5)		2.05E-02 lb/bu		
Anhydrous Ammonium	2.7 percent	(1)		2.77E-02 lb/bu		Evaluated results of 104 field experiments
Ammonium Nitrate	0.44 percent	(1)		4.51E-03 lb/bu		
Ammonium Chloride or	0.25 percent	(1)		2.56E-03 lb/bu		
Urea	0.11 percent	(1)		1.13E-03 lb/bu		
Calcium Nitrate	0.07 percent	(1)		7.18E-04 lb/bu		
	1.2 percent	(2)		1.23E-02 lb/bu		
Corn	1.5 percent	(3)		1.54E-02 lb/bu		Cites Mosier, A. R. et al. 1986. Soil Losses of Dinitrogen and Nitrous Oxide from Irrigated Crops in Northeastern Colorado, Soil Science Society of America Journal, 50:344-348
Corn (Anhydrous Ammo	1.29 percent	(1)		1.32E-02 lb/bu		This data is specific to corn and anhydrous ammonium, so it will be used here.
NO Emission	0.79 percent	(2)		8.10E-03 lb/bu		

Notes: NO2 emissions vary by fertilizer type and crop. Reference 1 gives a value for anhydrous ammonia fertilized corn. Since this data most closely represents average practices, and since the value is consistent with other results, it is used in the inventory.

Table 25 Pesticide and Nutrient Loss to Surface and Groundwater

- (1) Giotfelly, D.E., et al. 1984. Atrazine and Simazine Movement to the Wye River Estuary, Journal of Environmental Quality, 13:115-121
- (2) Bowman, B.T., et al. 1994. Transport of Herbicides and Nutrients in Surface Runoff from Corn Cropland in Southern Ontario Canadian Journal of Soil Science, 74(1):59-66, 1994
- (3) Buhler, D.D., et al. 1993. Water Quality: Atrazine and Alachlor Losses from Subsurface Tile Drainage of a Clay Loam Soil, Journal of Environmental Quality, 22:583-588, 1993
- (4) Battaglin, W.A., D.A. Goolsby, and D.K. Mueller. 1994. Relations Between Use, Concentration, and Transport of Agricultural Chemicals in the Mississippi River Basin, in Proceedings of the Annual Summer Symposium of the American Water Resource Association, Effects of Human Induced Changes on Hydrologic Systems, June 26-29, 1994, Jackson Hole, Wyoming.
- (5) Goolsby, D.A., E.M. Thurman, M.L. Pomes, and W.A. Battaglin. 1999. Temporal and Geographic Distribution of Herbicides in Precipitation in the Midwest and Northeast United States, 1990-1991, in Proceedings of the Fourth National Conference on Pesticides, New Directions in Pesticide Research, Development and Policy, November 1-3, 1993, Blacksburg, Virginia.

(6) United States Geological Survey. 1993. Selected Papers on Agricultural Chemicals in Water Resources of the Midcontinental United States, U.S.G.S. Open-File Report 93-418, U.S. G.S., Denver, CO.

(7) The Fertilizer Institute. 1982. The Fertilizer Handbook

Pesticides are transported from the point of application by several methods: surface runoff, leaching, volatilization, and direct airborne dispersal of pesticide which does not reach the target. These pesticides can be detected in surface water, groundwater, and rainwater. References 5 and 6 give information on the prevalence of pesticides in rainwater samples in the midwest. Detection of pesticides and pesticide metabolites is common, and concentrations may reach as high as Federal limits on drinking water concentrations. The total quantity of pesticides found in rainwater is small relative to applications (less than 1%) and does not account for total air emissions of pesticides. It is suggested in these studies that degradation, dry deposition, and drift outside of the study area may account for the remaining air emissions of pesticides. These air emissions have been quantified in Table 42. It should be noted that air emissions of pesticides which appear in rainfall also serve as a pesticide load on surface water.

Pesticides also appear in near surface aquifers. The concentrations found in groundwater are generally much smaller than surface water concentrations. No data has been identified which tracks aquifer loading as a fraction of total pesticide use in a particular region. Because this value is probably small relative to surface water loads, it will be treated as negligible. The data below thus give a gross quantification of pesticide flux to water systems in the midwest.

LCI Component	Raw Input Quantity	Units	Source	Notes
Herbicides Atrazine	2.50%	Percent	(1)	Midrange loss of atrazine for years in which significant rainfall occurred within two weeks of application
	0%	Percent	(2)	
	6%	Percent	(2)	Up to this level when rain immediately follows application
	1.53%	Percent	(4)	Annual average based on Mississippi Basin loadings and associated use levels.
Melachlor	0%	Percent	(2)	Up to this level when rain immediately follows application
	4%	Percent	(2)	
Alachlor	0.79%	Percent	(4)	Annual average based on Mississippi Basin loadings and associated use levels.
	0.22%	Percent	(4)	Annual average based on Mississippi Basin loadings and associated use levels.
Cyanazine	1.66%	Percent	(4)	Annual average based on Mississippi Basin loadings and associated use levels.
Nitrates	15.32%	Percent	(4)	Annual average based on Mississippi Basin loadings and associated use levels.
Phosphorous	1.00%	Percent	(7)	Rough estimate given as less than 1%
Potassium	3.50%	Percent	(7)	Rough estimate given as midway between N (6%) and P (1%)
Subsurface IaAlachlor	0.10%	Percent	(3)	Subsurface loss only
Atrazine	0.10%	Percent	(3)	

Application rates for insecticides are similar to those for herbicides (generally on the order of 1 lb/acre) but the fraction of acreage treated is much smaller (8% for chlorpyrifos and terbufos compared to 65% for atrazine). This may to some degree explain the lower frequency of detections of insecticides. Reference 6 includes results from samples taken on 8 river systems with the most frequently detected of the top three corn insecticides, fonofos, occurring in a maximum of 34 percent of samples (Illinois River). By comparison virtually all samples from all rivers had detectable quantities of atrazine and metolachlor. Other insecticides, such as diazinon and carbofuran were more prevalent. Because detailed estimates of the fraction of insecticides entering surface water systems have not been made, a rough approximation of 1% will be used.

Table 26 PM-10 Fugitive Emissions from Corn Production

(1) AP-42 Compilation of Air Pollutant Emission Factors, 5th Edition Chapter 9.3.2, Grain Harvesting.

(2) U.S. Environmental Protection Agency. 1994. National Air Pollutant Emission Trends, Office of Air Quality, EPA-454/R-94-027.

(3) United States Department of Agriculture, National Agricultural Statistics Service, Crop Production: 1994 Summary, Cr P-2-1(95), January 1995.

(4) United States Department of Agriculture, 1994 (revised 1995), Summary Report: 1992 National Resources Inventory, USDA Natural Resources Conservation Service and the Iowa State University Statistical Laboratory.

Year 1993	Source	Raw Input Quantity 1993	Raw Input Quantity 1987	Units	Notes
	Fugitive PM- (2) from Agricultural Cropland	6,842	7,338	thousand short tons	
	Cultivated Nd(4)	325,462	350,908	thousand acres	As a check on this number, area planted in 1993 can be taken from reference (3). This totals 259,404 thousand acres, but excludes hay production, for which harvested area is given. Adding hay harvested area gives rough estimate of total planted area of 319,029 thousand acres, similar to the NRI value.
	PM-10 Emiss(calculated)	0.0210	0.0209	short tons/acre	
	PM-10 Emiss(calculated)	42.045	41.823	lb/acre	
	Average value		41.93	lb/acre	0.348 lb/bu

Notes: Reference (2) uses methods described in method (1) to estimate fugitive dust emissions. These can be highly variable dependent on weather conditions. Because reference (4) only gives estimates in 5 year intervals, only two years worth of values can be estimated. Other sources can be used to estimate total cropland, but it is not clear which source of data is most appropriate. The PM-10 emissions are also based on factors only for agricultural tilling. Particulate is also emitted from grain harvesting operations. Reference (1) also gives emission factors for these operations for sorghum. The calculation below shows that these emissions are negligible with respect to the values estimated above. The emission rate is a general factor for cropland, but lacking additional data is used as a surrogate for emissions from corn cropland.

Sorghum Harvesting Emissions (reference 1, Table 9.3.2)

Item	Value	Units	Value	Units
Emission Rate				
Harvest Mac	6.5	lb/sq mile	0.01016	lb/acre
Truck Loadin	0.13	lb/sq mile	0.00020	lb/acre
Field Transpo	1.2	lb/sq mile	0.00188	lb/acre
Total	7.83	lb/sq mile	0.01223	lb/acre

Table 27 Emissions from Energy Consumption in Nitrogenous Fertilizer Manufacture

- (1) Energy Information Administration, 1994, Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).
- (2) United States Environmental Protection Agency, 1995, Compilation of Air Pollutant Emission Factors, AP-42.
- (3) United States Department of Energy, Energy Information Administration, 1994, Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.
- (4) United States Department of Energy, Energy Information Administration, 1993, Annual Energy Review: 1993, DOE/EIA-0384(93).
- | Energy for Nonfuel Purposes (MECSRaw Input Nitrogenous Fertilizers | Units Quantity | Transformed Units Input Quantity | Notes: |
|--|----------------|----------------------------------|-----------------|
| Natural Gas | 289 Tbu | 52.07% | Feedstock Share |

Total 290 Tbtu

Energy for Heat, Power, etc. (MECS Table A4)

Natural Gas 266 Tbtu
Electricity 10 Tbtu
Other 4 Tbtu
47.93% Fuel Share

Total Primary Energy Consumption (MECS Table A1)

Natural Gas 555 Tbtu
Electricity 10 Tbtu
Other 588 Tbtu

Large Industrial Boiler Emission Factors (AP-42, Tables 1.4-1 to 1.4-3)

SO ₂	0.6 lb/million cubic ft	0.00058 lb/million btu
NO _x	550 lb/million cubic ft	0.53295 lb/million btu
Uncontrolled	81 lb/million cubic ft	0.07849 lb/million btu
Controlled-Lo NO _x	53 lb/million cubic ft	0.05136 lb/million btu
Controlled-FGR	67 lb/million cubic ft	0.06492 lb/million btu
Average Controlled	308.5 lb/million cubic ft	0.29893 lb/million btu
Average	40 lb/million cubic ft	0.03876 lb/million btu
CO	13.7 lb/million cubic ft	0.01328 lb/million btu
PM-10	0.289 lb/million cubic ft	0.00028 lb/million btu
Methane	1.41 lb/million cubic ft	0.00137 lb/million btu
Non-methane VOC's	14.47 million metric ton	116.9 lb/million btu
CO ₂		
Heat Content of Natural Gas (AER, T	1,032 Btu/cubic foot	

This factor is given as the sum of filterable and condensable particulate. All PM emissions from N.G. consumption are thought to be < 10 microns in diameter

Emissions from the Use of N.G. in the Manufacture of Fertilizer per Unit Corn Production

SO ₂	6.37E-06 lb/bu
NO _x	3.28E-03 lb/bu
CO	4.25E-04 lb/bu
PM-10	1.46E-04 lb/bu
Methane	3.07E-06 lb/bu
Non-methane VOC's	1.50E-05 lb/bu
CO ₂	1.28 lb/bu

Notes: The share of N.G. used as feedstock for nitrogenous fertilizer manufacture vs. fuel is used to reduce emissions estimates to account for N.G. not consumed in boilers. Emission factors are converted into units of lb/million btu, which are multiplied by energy consumption and share of energy used as fuel. Emissions from the consumption of electricity by the industry will be calculated by the electricity module.

N.G. is used as a feedstock through a reforming process to produce hydrogen gas. This is the predominate process for ammonia production in the U.S. The hydrogen is reacted with nitrogen to form ammonia. This process results in the production of carbon dioxide and carbon monoxide. Carbon monoxide can be converted back to carbon dioxide through the water-gas shift reaction. Carbon dioxide has industrial use in several areas including the manufacture of urea from ammonia, but some carbon dioxide is emitted from the process. These and other process related emissions are treated in Table 35.

Table 28 Emissions from Diesel Consumption in Limestone Production and Farm Input Hauling

- (1) Boynton, Robert S. 1980. Chemistry and Technology of Lime and Limestone, Second Edition, John Wiley and Sons, Inc., New York.
- (2) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(3) U.S. Department of the Interior. Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

(4) USDA. 1995.

(5) Blankenhorn, Paul R., et al. 1986. Net Financial and Energy Analyses for Producing Populus Hybrid Under Four Management Strategies: First Rotation, Oak Ridge Nat'l Laboratory, ORNL/Sub/79-07928/1.

(6) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

Reference (2) suggests that of 315.45 kcal/kg energy input to limestone production, 300 kcal/kg is for transportation of the limestone to the user. Reference (4) on the other hand lists fuel type for lime split between natural gas, diesel, and coal, suggesting that transportation is not the major area for energy consumption. Reference (5) also explicitly states that energy use estimates for lime production include energy for mining, production, transportation, storage, and transfer. Because reference (2) is most explicit about energy use, emissions from the production of lime will be estimated based on truck emission factors for diesel trucks. It is also assumed that diesel fuel use by the phosphatic and potassium fertilizer industries is also consumed in trucks.

Vehicle CapaRaw Input Quantity	Units	Source	Transformed QUnits
Light Diesel T	10,000 lb	BMI Transport Model	
Heavy Diesel	42,000 lb	BMI Transport Model	

Vehicle Usage Rates	50.00% percent	(3)	Notes:
Light Diesel T	50.00% percent	(3)	My guess based on zero data
Heavy Diesel	50.00% percent	(3)	

Mileages	7.10 Miles/gallon	BMI Transport Model
Short Haul D	5.30 Miles/gallon	BMI Transport Model
Long Haul Di		
Diesel Energy	5.825 Million Btu/ba(6)	

Vehicle Registration Mix: January 1 & emissions factors , g/mile													Product of we
Gas Trucks					Light Duty Diesel				Heavy Diesel Trucks				
Model Year -	Fraction	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	NOx	
Model Year -	0	2.8	12.6	4.4	0.008	0.3	1.2	0.9	0.031	2.4	7.9	11	Model Year -
Model Year -	0.136	2.9	13.2	4.5	0.006	0.3	1.2	0.9	0.007	2.5	8.3	11.1	Model Year -
Model Year -	0.116	3.1	14.6	4.8	0.008	0.4	1.2	0.9	0.008	2.6	9.1	11.5	Model Year -
Model Year -	0.099	3.2	15.6	4.9	0.011	0.4	1.3	1	0.01	2.7	9.9	12	Model Year -
Model Year -	0.085	3.4	16.5	5.1	0.017	0.4	1.3	1	0.012	2.8	10.5	12.2	Model Year -
Model Year -	0.072	3.6	17.7	5.4	0.023	0.5	1.4	1	0.014	2.9	11.1	12.5	Model Year -
Model Year -	0.062	3.7	18.4	5.5	0.029	0.5	1.4	1.1	0.017	3	11.6	12.7	Model Year -
Model Year -	0.053	3.8	19.1	5.6	0.035	0.5	1.4	1.1	0.021	3.1	12.1	12.9	Model Year -
Model Year -	0.045	3.9	19.7	5.7	0.041	0.5	1.5	1.1	0.025	3.2	12.5	13.1	Model Year -
Model Year -	0.038	4.8	41.6	5.2	0.047	0.6	1.5	1.1	0.03	3.3	13.2	17.9	Model Year -
Model Year -	0.033	5.2	50.2	5.2	0.053	0.6	1.5	1.2	0.036	4	13.7	18.2	Model Year -
Model Year -	0.028	12.8	158.20	5.6	0.059	0.6	1.6	1.6	0.043	5.6	14.8	18.9	Model Year -
Model Year -	0.024	13	160.40	5.6	0.065	0.6	1.6	1.6	0.051	5.7	15.1	18.9	Model Year -
Model Year -	0.02	13.1	165.20	5.7	0.071	0.6	1.6	1.7	0.061	5.8	15.4	18.9	Model Year -
Model Year -	0.018	13.2	167.80	5.7	0.077	0.7	1.7	1.7	0.073	6.7	16.9	20.5	Model Year -
Model Year -	0.015	13.8	182.5	6.1	0.083	0.7	1.7	1.9	0.088	6.8	17.2	20.5	Model Year -
Model Year -	0.013	13.9	184.80	6.1	0.089	1.4	2.4	1.9	0.105	7.3	20.2	24.8	Model Year -
Model Year -	0.011	18.3	211.10	6.4	0.095	1.4	2.5	2	0.126	7.4	20.5	24.8	Model Year -
Model Year -	0.009	19.8	241.30	7.3	0.101	1.5	2.5	2	0.151	7.5	20.7	24.8	Model Year -
Model Year -	0.045	19.9	243.30	7.4	0.027	1.5	2.5	2	0	7.5	20.9	24.8	Model Year -
Weighted Av	92.20%	5.9	53.3	5.3	94.50%	0.5	1.4	1.1	90.90%	3.7	12.1	14.6	sum

Emission Factors Raw Input QUnits

Short Haul D Hydrocarbons	0.5 g/mile
Carbon Monoxide	1.4 g/mile
NOx	1.1 g/mile
Long Haul D Hydrocarbons	3.7 g/mile
Carbon Monoxide	12.1 g/mile
NOx	14.6 g/mile

Emissions	
Hydrocarbons	0.00043 lb/bu
Carbon Monoxide	0.00138 lb/bu
NOx	0.00161 lb/bu
CO2	0.29174 lb/bu

Table 29 Emissions from Farm Equipment

- (1) U.S. EPA. 1991. Nonroad Engine and Vehicle Emission Study-Report, EPA 460/3-91-02.
- (2) U.S. EPA. 1991. Nonroad Engine and Vehicle Emission Study-Appendix (sp): Draft, 21A-2001 (NTIS #PB92-104462).
- (3) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review. 1993, DOE/EIA-0384(93).
- (4) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

Farm Equipm	Units	Raw Input Quantity	HC	CO	NOx	SOx	Particulate	Aldehydes	Source	Notes
Diesel Tractor	lb/1000 gallons	63.55	175	438.59	31.2	45.7	12 (2)			Weighted by factors for large 2WD, small 2WD, and 4WD tractors.
Diesel Non-Tlb	lb/1000 gallons	72.52	171	435	5.28	51.3	10.2 (2)			Diesel HC values include exhaust and crankcase emissions.
Gasoline Tra	lb/1000 gallons	178.85	4,456	213,232	5.31	8	6.8 (2)			Gasoline HC values include exhaust, crankcase, and refueling emissions.
Gasoline Nortb	lb/1000 gallons	192.15	4,456	213,232	5.28	6.86	4.1 (2)			

Carbon Dioxide Emission Factors

Raw Input Quantity	Units	Source	Transformed Units	Transformed Units
Diesel	19.95 Million mtions(4)		43.98 lb C/million bt	161.16 lb CO2/million btu
Gasoline	19.41 Million mtions(4)		42.79 lb C/million bt	156.79 lb CO2/million btu

Energy Value Raw Input Quantity

Transformed Units

Raw Input Quantity	Units	Source	Transformed Units
Diesel	5.825 Million Btu/ba(3)		138,690 Btu/gallon
Motor Gasoli	5.253 Million Btu/ba(3)		125,071 Btu/gallon

Direct On-Fa Raw Input Quantity

Transformed Units

Raw Input Quantity	Units	Source	Transformed Units
Diesel	9,583 Btu/bu	Tables 13 and 15	0.069 Gallons/bu
Motor Gasoli	3,621 Btu/bu	Tables 13 and 15	0.029 Gallons/bu

Emissions froQuantity

Units

Raw Input Quantity	Units
HC	9.57E-03 lb/bu
CO	1.41E-01 lb/bu
NOx	3.65E-02 lb/bu

SOx	2.31E-03 lb/bu
Particulate	3.74E-03 lb/bu
Aldehydes	4.70E-04 lb/bu
CO2	2.11 lb/bu

Notes: Reference (2) lists percentage energy output estimates for diesel equipment. According to that data about 85% of energy use is by tractors. Since non-tractor equipment includes many categories that would not be used on corn farms, such as cotton pickers, orchard sprayers, and mowers, the percentage of energy use for non-tractors on corn farms would be quite small. Also, the difference between tractor and non-tractor emission factors is small. For this reason, emissions estimates are based on the weighted factors for tractors.

Diesel energy use in tractors is taken from Table . Because the total value in this table includes diesel use in input hauling, which is accounted for in a separate table, the individual components for on farm use must be pulled out of the table separately. Diesel use to produce seed is also included in these calculations.

Table 30 Emissions from Natural Gas and LPG Use for Corn and Seed Production

(1) U.S. EPA, AP-42, Sections 1.4 and 1.5.

(2) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

Natural gas and LPG are used in corn farming for drying the corn to acceptable moisture content levels for storage, usually 12 to 13%. The EPA publishes particulate emission factors for feed dryers, but does not include emission factors for the products of combustion. In order to estimate emissions from the consumption of natural gas and LPG, factors for uncontrolled commercial boilers will be applied to the direct use of natural gas and LPG on farms, and to the use of natural gas in seed production.

Emission Factors - Natural Gas	Raw Input	Units	Source	Transformed Units
NOx	100	lb/million cubic ft(1)		9.69E-02 lb/million btu
SOx	0.6	lb/million cubic ft(1)		5.81E-04 lb/million btu
PM-10	12	lb/million cubic ft(1)		1.16E-02 lb/million btu
CO	21	lb/million cubic ft(1)		2.03E-02 lb/million btu
CO2	14.47	million metric ton(2)		116.89 lb/million btu
Non-Methane VOC's	3.83	lb/million cubic ft(1)		3.71E-03 lb/million btu
Methane	1.97	lb/million cubic ft(1)		1.91E-03 lb/million btu

Natural Gas Use In Corn Farming an 3,685 Btu/bu From Tables 13 and 15

Emissions

NOx	3.57E-04	lb/bu
SOx	2.14E-06	lb/bu
PM-10	4.28E-05	lb/bu
CO	7.50E-05	lb/bu
CO2	4.31E-01	lb/bu
Non-Methane VOC's	1.37E-05	lb/bu
Methane	7.04E-06	lb/bu

Emission Factors -LPG	Raw Input	Units	Source	Transformed Units
NOx	14	lb/million cubic ft(1)		1.36E-02 lb/million btu
SOx	0.018	lb/million cubic ft(1)		1.74E-05 lb/million btu
Particulate	0.4	lb/million cubic ft(1)		3.88E-04 lb/million btu
CO	1.9	lb/million cubic ft(1)		1.84E-03 lb/million btu
CO2	17.16	million metric ton(2)		138.62 lb/million btu
Organic Compounds	3.83	lb/million cubic ft(1)		3.71E-03 lb/million btu

LPG Use In Corn Farming and Seed 3,210 Btu/bu From Tables 13 and 15

Emissions

NOx 4.35E-05 lb/bu
 SOx 5.60E-08 lb/bu
 Particulate 1.24E-06 lb/bu
 CO 5.91E-06 lb/bu
 CO2 4.45E-01 lb/bu
 Organic Compounds 1.19E-05 lb/bu

Total Emissions

NOx 4.01E-04 lb/bu
 SOx 2.20E-06 lb/bu
 PM-10 4.28E-05 lb/bu
 Particulate 1.24E-06 lb/bu
 CO 8.09E-05 lb/bu
 CO2 8.76E-01 lb/bu
 Non-Methane VOC's 2.56E-05 lb/bu
 Methane 7.04E-06 lb/bu

Table 31 Unallocated Emissions from Fuels

(1) United States Department of Energy, Energy Information Administration, 1993, Annual Energy Review: 1993, DOE/EIA-0384(93).

In this table all fuel use for which a specific emission factor could not be found are totalled, and general emission factors used to estimate emissions. This includes fuel use for P and K fertilizer use, fuel use for pesticides and seed use of coal, and oil.

Sum of Previ Total	Units	Table 8 Fertilizer Packag	Table 12 Pesticide ProDirect Use	Table 13 Nitrogen (allocated)	Table 14 Phosphates (allocated)	Potash	Table 15 Seed Product Limestone/Sulfur (allocated)	Table 16 (allocated)
N.G.	1,836 Btu/bushel	0	875 (allocated)	0	0	425	536 (allocated)	0
Diesel	0 Btu/bushel	0	0 (allocated)	0	0	0	0 (allocated)	0
LPG	0 Btu/bushel	0	0 (allocated)	0	0	0	0	0
Coal	522 Btu/bushel	0	522	0	0	0	0	0
Oil	1,870 Btu/bushel	0	1,300	0	0	442	0	0
Gasoline	0 Btu/bushel	0	0 (allocated)	0	0	0	0 (allocated)	0
Total Fuel	4,228 Btu/bushel	0	2,697	0	0	867	536	128

Emission FacN.G.

NOx 140 lb/million cub 13.7 lb/ton 20 lb/thousand gallons
 SOx 0.80 lb/million cub 57 lb/ton 143.60 lb/thousand gallons
 PM-10 14 lb/million cub 12.4 lb/ton 1 lb/thousand gallons
 CO 35 lb/million cub 5 lb/ton 5 lb/thousand gallons
 CO2 14 Million Mtons 25.58 Million Mtons 19.95 Million Mtons C/Quad
 Non-Methane 2.78 lb/million cub 0.05 lb/ton 0.34 lb/thousand gallons
 Methane 3.02 lb/million cub 0.06 lb/ton 0.216 lb/thousand gallons
 Particulate 14 lb/million cub 17 lb/ton 2 lb/thousand gallons

Energy ValueQuantity
 N.G. Units Source
 Coal 1,032 Btu/cubic foot Transformed
 22.25 million btu/fo (1) 22.25 million btu/ton

Oil 5.83 million btu/ba(1) 0.14 million btu/gallon

Emission Factors G.

Coal Oil

NOx	0.1357	0.6157	0.1442
SOx	0.0006	2.5618	1.0354
PM-10	0.0133	0.5573	0.0072
CO	0.0339	0.2247	0.0361
CO2	116.89	206.64	161.16
Non-Methane	0.0027	0.0022	0.0025
Methane	0.0029	0.0027	0.0016
Particulate	0.0133	0.7640	0.0144

Emissions in lb/bu

NOx	8.40E-04	lb/bu
SOx	3.27E-03	lb/bu
PM-10	3.29E-04	lb/bu
CO	2.47E-04	lb/bu
CO2	0.6238	lb/bu
Non-Methane	1.07E-05	lb/bu
Methane	9.68E-06	lb/bu
Particulate	4.50E-04	lb/bu

Notes: Emissions factors used for natural gas are for uncontrolled small industrial boilers. Emission factors for oil are for uncontrolled distillate oil fired commercial boilers. Emission factors for coal are for uncontrolled spreader stokers and assumes 1.5% sulfur content. The PM-10 value for coal is from AP-42 table 1.1-8 and differs slightly from the value in AP-42 table 1.1-3.

Table 32 Material resource Requirements for Fertilizer and Herbicide Manufacture

(1) The Fertilizer Institute. 1982. The Fertilizer Handbook

(2) Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzton Nyangilo. 1993. Energy Use in Synthetic Agricultural Inputs: Revisited. Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

(3) U.S. Department of the Interior, Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

Nitrogen

Nitrogenous fertilizers are primarily manufactured from ammonia, and for corn the predominant form is simply anhydrous ammonia.

The most common manufacturing method for ammonia uses natural gas as a feedstock. The use of this natural gas has been accounted for in the energy consumption estimates (the nitrogen in the ammonia comes from the air).

Nitrogen solutions are the next most common N fertilizer type used in corn production. Nitrogen solutions are produced from urea and ammonium nitrate. Ammonium nitrate is again manufactured from ammonia, for which the feedstock energy use is captured in the natural gas energy consumption estimates.

Urea is produced from ammonia and carbon dioxide. Since carbon dioxide is a byproduct of steam reforming of methane (to produce ammonia) and since carbon dioxide is not typically considered a "resource", the material resource requirements for N fertilizers are entirely captured by the use of natural gas as a feedstock.

Phosphatic Fertilizers

Phosphorous is produced from calcium phosphate rock deposits found primarily in Florida and North Carolina. The production of 1 ton of P2O5 requires 3.2 tons of phosphate rock (2). On this basis the resource consumption for corn production is calculated from Table 2, or 1.25 lb/bushel

Potassium

Potassium is mined from deep potassium ore beds or recovered from natural brines such as Searles Lake, CA. The predominant source are deep mines, where potassium is recovered as KCl mixed with other salts. The quantity of KCl used to produce a unit of K₂O can be calculated from the stoichiometry

$$0.37 \text{ lb/bushel}$$

Sulfur

Sulfur is used both as a primary nutrient in corn production, and also in the manufacture of potassium fertilizers. In fertilizer production sulfur is burned then reacted to form sulfur trioxide. The sulfur trioxide is then mixed with dilute sulfuric acid to form a concentrated solution of sulfuric acid. Finally phosphate rock is treated with sulfuric acid to produce phosphoric acid. The sulfuric acid reacts with phosphate rock according to the simplified reactions:

$$\text{Ca}_3(\text{PO}_4)_2 + 3\text{H}_2\text{SO}_4 + 6\text{H}_2\text{O} \rightarrow 2\text{H}_3\text{PO}_4 + 3\text{CaSO}_4 \cdot \text{H}_2\text{O}$$

The phosphorous is then burned or oxidized to phosphoric acid. According to information provided by Joyce Ober at the Bureau of Mines, one ton of DAP (the most common source of phosphates in Iowa), requires about 431 to

$$0.918 \text{ lb sulfur per pound of P}_2\text{O}_5$$

$$\begin{aligned} &0.01 \text{ lb/bu direct application} \\ &0.43 \text{ lb/bu from phosphoric acid manufacture} \\ &0.44 \text{ lb/bu total} \end{aligned}$$

Sulfur is produced in the U.S. primarily from recovered sulfur at petroleum refineries, natural gas processing plants, and coking plants, which account for 55% of domestic consumption in 1993 (3). About 21% of sulfur production is through Frasch process sulfur mining. The remaining sulfur came from byproduct sulfuric acid, primary pyrites, hydrogen sulfide, and sulfur dioxide.

Table 33 Emissions of PM-10 from Crushed Stone Processing Operations

U.S. EPA, AP-42, Table 11.19.2-2.

Units are lb/ton of stone				
PM-10 Emission Category	Controlled	Uncontrolled	Controlled/Uncon	Control Efficiency
Screening	8.40E-04	0.015	5.60%	94.40%
Primary Crus	-	-	-	-
Secondary C	-	-	-	-
Tertiary Crus	5.90E-04	0.0024	24.58%	75.42%
Fines Crus	2.00E-03	0.015	13.33%	86.67%
Fines Screen	2.10E-03	0.071	2.96%	97.04%
Conveyor Tra	4.80E-05	0.0014	3.43%	96.57%
Wet Drilling:	-	8.00E-05	-	-
Truck Unload	-	1.60E-05	-	-
Truck Loadin	-	0.0001	-	-
Total (lb/ton o	5.58E-03	0.104996	-	-
Total (lb/bu c	3.58E-06	6.73E-05	-	-

Notes: Based on this data the PM-10 emissions from stone processing are negligible with comparison to PM-10 emissions from Ag. operations in corn production (Table 26). Thus this emission is not added to total PM-10 emissions.

Table 34 Emissions from Phosphate Rock Processing

(1) U.S. EPA, AP-42, Tables 11.21-2 and 11.21-3

(2) The Fertilizer Institute, 1982. The Fertilizer Handbook

Units of lb/ton of total phosphate rock feed

Emission	SO ₂	CO ₂	CO	Filler PM-10
Dryer	-	86	0.34	4.8
Calciner	-	-	-	15
Calciner With	0.0069	230	-	-

Assuming that output is roughly equivalent to feed quantity, emissions can be converted into lb/bu of corn using the relationship that 3.5 tons of phosphate rock are used to produce one ton of P2O5 (2).

Units of lb/bu of corn				
Emission	SO ₂	CO ₂	CO	Filler PM-10
Dryer	-	0.06	2.33E-04	3.29E-03
Calciner	-	-	-	1.03E-02
Calciner With	4.73E-06	0.16	-	-
Total	4.73E-06	0.22	2.33E-04	1.36E-02

Table 35 Process Related Emissions from Ammonia Manufacture for Nitrogenous Fertilizers

U.S. EPA, 1995, AP-42, Fifth Edition, Table 8.1-1.

All units are in lb/ton of ammonia produced				
Emission	SO ₂	NH ₃	CO ₂	Total Organic Compounds
Desulfurizatio	13.8	0.0576	-	7.2
Carbon Dioxi	2	-	2	2.440
Condensate Steam Stripper	-	-	2.2	6.8
				1.2

Since nitrogenous fertilizer use is given in terms of the nitrogen quantity, these emission factors can be converted into terms of lb/ton of nitrogen. This is done using the ratio of the molecular wt. of ammonia to the molecular wt. of nitrogen. The converted emission factors are then multiplied by the total nitrogen use, in tons.

Molecular wt	14.01
Molecular wt	1.01
Molecular wt	17.03
Ratio NH ₃ :N	1.22

All units are in lb/ton of nitrogen produced				
Emission	SO ₂	NH ₃	CO ₂	Total Organic Compounds
Desulfurizatio	16.78	0.07	-	8.75
Carbon Dioxi	2.43	-	2.43	1.26
Condensate Steam Stripper	-	-	2.67	8
				1.46

Finally emissions are converted to units of lb of pollutant per bushel of corn produced using the nitrogen fertilizer use rate in Table 2.

All units are in lb/bu of corn				
Emission	SO ₂	NH ₃	CO ₂	Total Organic Compounds
Desulfurizatio	0.0086	3.59E-05	-	0.0045
Carbon Dioxi	0.0012	-	0.0012	1.5217
Condensate	-	-	0.0014	0.0042
Total	0.0099	3.59E-05	0.0026	1.5259
				0.0059

Notes: Since we know the amount of methane (and hence carbon) used as a feedstock for nitrogen fertilizer production we can calculate a bound on process related CO₂ emissions.

Feedstock M	21.78 million btu/ton ammonia
	26.48 million btu/ton N
	13.241 Btu/lb N
Carbon per u	14.47 Million metric tons C/quad
	31.90 lb C/million btu
	116.89 lb CO ₂ /million btu
	1.55 lb CO ₂ /lb N
	3.095 lb CO ₂ /ton N

This shows that the CO₂ emission factors for process related emissions are based on the carbon value of the feedstock, and the assumption that virtually all carbon is emitted, not used for other purposes.

Table 36 Process Emissions from Urea Manufacture

(1) U.S. EPA, 1995. AP-42, Fifth Edition, Table 8.2-1.

(2) The Fertilizer Institute, 1982. The Fertilizer Handbook

Emission Factors (lb/ton urea)		Ammonia	
Type of Oper	Particulate	Controlled	Uncontrolled
Solution Formation and			
Concentratio	0.021	-	18.46
Nonfluidized Bed Prilling			
Agricultural G	3.8	0.063	0.87
Fluidized Bed Prilling			
Agricultural G	6.2	0.78	2.91
Drum Granul	241	0.234	2.15
Rotary Drum	7.78	0.2	0.051
Bagging	0.19	-	-
Percentage N	46%	Source	
	(2)		

Emission Factors (lb/ton N)		Ammonia	
Type of Oper	Particulate	Controlled	Uncontrolled
Solution Formation and			
Concentratio	0.046	-	40.130
Nonfluidized Bed Prilling			
Agricultural G	8.261	0.137	1.891
Fluidized Bed Prilling			
Agricultural G	13.478	1.696	6.326
Drum Granul	523.913	0.509	4.674
Rotary Drum	16.913	0.435	0.111
Bagging	0.413	-	-

Physical and Chemical Characteristics of Nitrogen Solution
(28% N in solution)

Urea N: Anm	1.04 (unitless)
Urea N	50.98%
Ammonium N	49.02%

Direct Urea N	0.10 lb/bu	41.62% percent
Urea N Use R	0.13 lb/bu	58.38% percent
Total N Use f	0.23 lb/bu	

Emissions (lb/bu)		Ammonia	
Particulate		Uncontrolled	Controlled
Type of Oper	Controlled		
Solution Formation and Concentration	5.24E-06	4.60E-03	-
Nonfluidized Bed Prilling			
Agricultural G	9.48E-04	1.57E-05	2.17E-04
Fluidized Bed Prilling			
Agricultural G	1.55E-03	1.95E-04	7.26E-04
Drum Granul	6.01E-02	5.84E-05	5.36E-04
Rotary Drum	1.94E-03	4.99E-05	1.27E-05
Bagging	4.74E-05	-	-
Average of P	1.25E-03	1.05E-04	4.71E-04
Total including solution formation, and prilling	1.25E-03	#VALUE!	4.80E-03

Notes: The only significant particulate emission source relative to other sources in corn production is uncontrolled emissions from drum granulation. By contrast controlled emissions are about 0.1% of uncontrolled emissions from this source. Furthermore, only a fraction of urea production is granular. More than 50% of urea is used in nitrogen solutions, in which case granulation is not required. Reference (1) also states that wet scrubbers are standard equipment for drum granulators. Based on this information it is assumed that particulate emissions from urea manufacture are negligible.

Ammonia emissions are not negligible. The emission factors for ammonia in urea formation and concentration are much larger than ammonia emission factors in ammonia manufacture. The total emission factor used here is generated on the assumption that all urea passes through the concentration operation, that solid urea is produced through uncontrolled prilling operations, and the average factor for the two types of prilling operations is used. Assumptions about the granulation method have little effect on the emission factor since granulation emissions are outweighed by solution formation and concentration emissions.

Table 37 Process Emissions from Ammonium Nitrate Manufacture

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.3-2.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Ammonium Nitrate is not itself an important fertilizer type in Iowa, suggesting that its use in corn production is limited. Ammonium nitrate is a constituent of nitrogen solutions, however, which are the second most common form of nitrogen application in Iowa. For this reason it is necessary to evaluate the significance of process related emissions from ammonium nitrate manufacture. These are limited to neutralizing and evaporation/concentration processes since it is not necessary to produced solid forms of ammonium nitrate for nitrogen solution manufacture.

Emission Factors (lb/ton)		Ammonia		Notes
Particulate		Uncontrolled	Nitric Acid Controlled	
Process				
Neutralizer	4.345	0.217	18.44	1.042
Evaporation/	0.52	-	16.97	-

Source

Ammonia emission factor given as range from 0.86 to 36.02. Nitric acid from 0.084 to 2
Ammonia emission factor given as range from 0.54 to 33.4.

Ammonium N	34% (2)			
Emission Factor (lb/ton N)				
Process	Particulate	Ammonia	Nitric Acid	
Neutralizer	Controlled	Uncontrolled	Uncontrolled	Controlled
Evaporation/	12.78	0.64	54.24	3.06
	1.53	-	49.91	-
Urea N: Amm	1.04 (unitless)			
Urea N	50.98%			
Ammonium N	49.02%			
Emission Rate (lb/bu)				
Process	Particulate	Ammonia	Nitric Acid	
Neutralizer	Controlled	Uncontrolled	Uncontrolled	Controlled
Evaporation/	8.23E-04	4.11E-05	3.49E-03	1.97E-04
Total	9.85E-05	-	3.21E-03	-
	9.21E-04	4.11E-05	6.71E-03	1.97E-04

Notes: Particulate emissions from ammonium nitrate manufacture are negligible relative to PM-10 emissions from tilling operations. Lacking data on the use of particulate controls, these emissions will not be included in total particulate or PM-10 emissions. Ammonia emissions are significant relative to emissions of ammonia from urea and ammonia manufacturing operations. Lacking additional data the sum of the mid-range values for uncontrolled ammonia emissions and controlled nitric acid emissions are used.

Table 38 Process Emissions from Ammonium Phosphate Manufacture

(1) U.S. EPA, 1995, AP-42, Fifth Edition, Table 8.5.3-1.

(2) The Fertilizer Institute, 1982, The Fertilizer Handbook

Emission Factors (lb/ton)				
Process	Particulate	Ammonia	Fluoride (as F)	SO ₂
Reactor/Amm	1.52	-	0.05	-
Dryer/cooler	1.5	0.02	0.04	-
Product sizin	0.06	0.08	0.002	-
Total Plant	0.68	0.14	0.04	0.08
Fraction P2O	46% (2)			
Emission Factors (lb/ton P2O5)				
Process	Particulate	Ammonia	Fluoride	SO ₂
Reactor/Amm	3.30	-	0.11	-
Dryer/cooler	3.26	0.04	0.09	-
Product sizin	0.13	0.17	0.004	-
Total Plant	1.48	0.30	0.09	0.174
Emission Rate (lb/bu)				
Process	Particulate	Ammonia	Fluoride	SO ₂

Reactor/Amm	6.47E-04	-	-	-
Dryer/cooler	6.39E-04	8.51E-06	-	-
Product sizer	2.55E-05	3.41E-05	8.51E-07	-
Total Plant	2.90E-04	5.96E-05	1.70E-05	3.41E-05

Note: For particulate and ammonia the total emission factor is not the sum of the process emission factors, but is instead an aggregate value from a different source. The EPA quality rating for these values is also high, as opposed to the process level values, for which it is low. As such, emissions for corn production are taken from the total plant row.

Table 39 Process Emissions from Nitric Acid Manufacture (used in ammonium nitrate manufacture)

(1) U.S. EPA, 1995, AP-42, Fifth Edition, Table 8.8-1.

(2) The Fertilizer Institute, 1982, The Fertilizer Handbook

Nitric acid is used in the manufacture of ammonium nitrate. Since these emissions are not included in the emissions from ammonium nitrate manufacture they are included here.

Emission Factors (lb/ton)

Source	NOx
Weak Acid P	57
New Source	3
Catalytic Reduction	
Natural Gas	0.4
Hydrogen	0.8
N.G./Hydroge	0.9
Extended Absorption	
Single-Stage	1.9
Dual-Stage P	2.1
Chilled Absor	2.2
High-Strengt	10

Ratio of HNO
(nitric acid to ammonium nitrate)
NH₃ + HNO₃ -> NH₄NO₃

Emission Factors (lb/ton ammonium nitrate)

Source	NOx
Weak Acid P	44.87
New Source	2.36
Catalytic Reduction	
Natural Gas	0.31
Hydrogen	0.63
N.G./Hydroge	0.71
Extended Absorption	
Single-Stage	1.50
Dual-Stage P	1.65
Chilled Absor	1.73
High-Strengt	7.87
Fraction N in	0.35

Emission Factors (lb/ton N)

Source	NOx
Weak Acid P	128.21
New Source	6.75
Catalytic Reduction	
Natural Gas	0.90
Hydrogen	1.80
N.G./Hydroge	2.02
Extended Absorption	
Single-Stage	4.27
Dual-Stage P	4.72
Chilled Absor	4.95
High-Strengt	22.49
Urea N: Anm	1.04 (unitless)
Urea N	50.98%
Ammonium N	49.02%

Emission (lb/bu)

Source	NOx
Weak Acid P	8.26E-03
New Source	4.35E-04
Catalytic Reduction	
Natural Gas	
Hydrogen	1.16E-04
N.G./Hydroge	1.30E-04
Extended Absorption	
Single-Stage	2.75E-04
Dual-Stage P	3.04E-04
Chilled Absor	3.19E-04
High-Strengt	1.45E-03
Total Excludi	9.84E-03

Notes: Uncontrolled emissions rates from weak acid plant tailgas are the only emissions that are significant relative to fuel related emissions from the corn production cycle. The uncontrol 19.38% of fuel related NOx emissions. While this would be a significant contribution many techniques are employed to reduce tail gas emissions including extended absorption and catalytic reduction. Also New Source Performance Standards for nitrogen emissions (expressed as N2O) for new and modified plants are 3 lb/ton of nitric acid. At this emission rate the NOx contributions from nitric acid manufac 1.02% of fuel related NOx emissions. Lacking information to accurately estimate actual controlled emissions, they will be neglected.

Table 40 Process Emissions from the Manufacture of Phosphoric Acid

(1) U.S. EPA, 1995. AP-42, Fifth Edition, Table 8.9-1.

(2) The Fertilizer Institute, 1982. The Fertilizer Handbook

Phosphoric acid used in fertilizer manufacture is produced primarily using a wet process method. The factors given below are for wet process manufacture.

Emission Factors (lb/ton P2O5)

Source	Controlled	Uncontrolled
Reactor	3.80E-03	0.38
Evaporator	4.40E-05	0.0044
Belt Filter	6.40E-04	0.064
Belt Filter Va	1.50E-04	0.015
Gypsum Sett-		

Emission Rate (lb/bu)		
Fluorine		
Source	Controlled	Uncontrolled
Reactor	7.44E-07	7.44E-05
Evaporator	8.62E-09	8.62E-07
Belt Filter	1.25E-07	1.25E-05
Belt Filter Va	2.94E-08	2.94E-06
Gypsum Sett -		
Total	9.08E-07	9.08E-05

Notes: Uncontrolled fluorine emissions from phosphoric acid manufacture are similar to controlled emissions from ammonium phosphate manufacture. For phosphoric acid, the control efficiency used is 99%, similar to the value given for the use of baghouses in GTSP manufacture. On this basis controlled emissions from phosphoric acid manufacture are only about 1% of controlled emissions from phosphoric acid manufacture. For the sake of consistency, and lack further data on the relative penetration of controls in this industry, the controlled emission rate is used.

Table 41 Process Emissions from Sulfuric Acid Manufacture (used in phosphoric acid manufacture)

(1) U.S. EPA, 1995, AP-42, Fifth Edition, Table 8.8-1.

(2) The Fertilizer Institute, 1982, The Fertilizer Handbook

Sulfuric acid is used in the manufacture of phosphoric acid which is used in the manufacture of phosphate fertilizers. Emission consist primarily of sulfur dioxide and acid mist. Sulfur dioxide emissions are primarily a function of the conversion efficiency from SO₂ to SO₃ in the plant.

Emission Factors (lb/ton sulfuric acid)

Conversion ESO ₂ Emissions	
93	96
94	82
95	70
96	55
97	40
98	26
99	14
99.5	7
99.7	4
100	0

Source

Sulfuric Acid 2.87 Conversion factor for sulfuric acid to DAP provided by Joyce Ober, sulfur specialist, Bureau of Mines

Emission Factor (lb/ton P₂O₅)

Conversion ESO ₂ Emissions	
93	275.52
94	235.34
95	200.9
96	157.85
97	114.8
98	74.62
99	40.18
99.5	20.09
99.7	11.48
100	0

Emission Rate (lb/bu)

Conversion ESO2 Emissions	
93	0.0540
94	0.0461
95	0.0393
96	0.0309
97	0.0225
98	0.0146
99	0.0079
99.5	0.0039
99.7	0.0022
100	0.0000

Notes: Sulfur dioxide emissions are highly correlated with conversion efficiency. Typical conversion efficiencies are given in AP-42 as 95 to 98%. Sulfur emissions can be controlled using standard sulfur capture technologies. New Source Performance Standards are also set quite low, at 4 lb/ton of product. Assuming that new plants comply with NSPS limits, but that old plants exist with higher emissions, the emission rate used here is at the upper end of conversion efficiency estimates.

Acid Mist Emission Factors (lb/ton H₂SO₄) (Where values are given as a range, the midrange is used)

Raw Material Uncontrolled		Controlled
Recovered S		0.574
Elemental S	-	0.128
Bright Virgin		1.7
Dark Virgin S		3.3
Spent Acid		2.3
		0.34

Acid Mist Emission Factors (lb/ton P₂O₅)

Raw Material Uncontrolled		Controlled
Recovered S		1.64738
Elemental S	-	0.36736
Bright Virgin		4.879
Dark Virgin S		9.471
Spent Acid		6.601
		0.9759

Acid Mist Emissions (lb/bu)

Raw Material Uncontrolled		Controlled
Recovered S		3.23E-04
Elemental S	-	7.19E-05
Bright Virgin		9.56E-04
Dark Virgin S		1.85E-03
Spent Acid		1.29E-03
		1.91E-04
Average		1.41E-03
Average (Co		1.01E-03

Notes: According to AP-42 about 81% of sulfuric acid production is from elemental sulfur burning. Average emission factors are calculated above using the elemental, bright virgin, and dark virgin sulfur factors.

The uncontrolled and controlled factors are then averaged.

Carbon Diox
8.1 lb/ton sulfuric acid
23.247 lb/ton P2O5
0.0046 lb/bu

Notes: Carbon dioxide emissions are negligible relative to other sources and are thus neglected.

Table 42 Air Emissions from Pesticide Use

- (1) U.S. EPA. 1995. AP-42, Fifth Edition, Section 9.2.2.
- (2) Personal Communication with David Pike, Agriculture Extensionist, University of Illinois, Department of Agronomy, September 26, 1995.
- (3) Personal Communication with Van Johnson, Pesticide Specialist, USDA NASS, September 28, 1995.
- (4) Personal Communication with Bob Hartzler, Iowa Ag. Extension, University of Iowa, September 22, 1995.
- (5) United States Department of Agriculture, Economic Research Service. 1994. Agricultural Resource and Environmental Indicators, USDA/ERS, Ag. handbook 705, Washington, D.C.
- (6) Personal Communication with Tom Lapp, Midwest Research Institute, September 29, 1995.

Product formulation data was provided by Van Johnson of the USDA, NASS.

Pesticide Types Used on Illinois Corn (2)

Pesticide Type	Active Ingredient	Brand	Formulation	Type	Formulation	Shlchlor	Atrazine	Fraction Prin	Fraction Inert	Ingredient	Fraction of To	Normalized FrPest.	use/bu coa i.	use/bu coAtrazine/bu c	Total VOC's (lb/bu corn)	
Herbicides	Alachlor	Bullet	liquid	4	2.5	1.5	29.99%	52.02%	30%	35.29%	4.72E-03	1.42E-03	8.49E-04	4.91E-04	4.91E-04	
		Lasso (4EC)	liquid	4	4	0	47.98%	52.02%	20%	23.53%	1.97E-03	9.43E-04	0.00E+00	2.05E-04	2.05E-04	
		Lariat (4F)	liquid	4	2.5	1.5	29.99%	52.02%	10%	11.76%	1.57E-03	4.72E-04	2.83E-04	1.64E-04	1.64E-04	
		Lasso Micro-micro-encapsulat	4	4	4	0	47.98%	52.02%	25%	29.41%	2.46E-03	1.18E-03	0.00E+00	2.56E-04	2.56E-04	
		Dual 4E	liquid	4	4	0	47.98%	52.02%	50%	50.00%	5.11E-03	2.45E-03	0.00E+00	5.32E-04	5.32E-04	
		Bicep 6L	liquid	6	3.33	2.67	39.94%	28.03%	35%	35.00%	4.30E-03	1.72E-03	1.38E-03	2.41E-04	2.41E-04	
		Dual 25G	granular	0.25	25	0	25.00%	75.00%	15%	15.00%	2.94E-03	7.36E-04	0.00E+00	5.52E-04	5.52E-04	
		Bicep 6L	liquid	6	2.67	3.33	32.03%	28.03%	25%	25.00%	4.30E-03	1.38E-03	1.38E-03	3.09E-04	3.09E-04	
		Atrazine 4L	liquid	4	4	0	47.98%	52.02%	52%	52.00%	6.78E-03	3.25E-03	7.04E-04	7.04E-04	7.04E-04	
		Bullet	liquid	4	1.5	2.5	17.99%	52.02%	15%	15.00%	4.72E-03	8.49E-04	8.49E-04	6.04E-04	6.04E-04	
Insecticides	Chlorpyrifos	Marksman	liquid	4	2.1	1.1	25.19%	52.02%	8%	8.00%	1.98E-03	4.99E-04	2.97E-04	2.97E-04	2.97E-04	
		Actual Atrazine											6.24E-03	6.80E-04	1.91E-03	
		Percent Accou											95.67%	Atrazine from	2.91E-03	
		Total Atrazin											6.24E-03	6.24E-03	6.24E-03	
		Cyanazine	Extrazine 4L	liquid	4	3	1	35.98%	52.02%	40%	42.11%	3.78E-03	1.36E-03	4.53E-04	3.93E-04	3.93E-04
			Extrazine 90Dry flowable	90	0.675	0.225	67.50%	10.00%	20%	21.05%	1.01E-03	6.80E-04	2.27E-04	2.82E-05	2.82E-05	2.82E-05
			Bladex 80WPwetttable powder	80	0.8	0	80.00%	20.00%	8%	8.42%	3.40E-04	2.72E-04	0.00E+00	1.70E-05	1.70E-05	1.70E-05
			Bladex 4L	liquid	4	4	0	47.98%	52.02%	12%	12.63%	8.50E-04	4.08E-04	0.00E+00	8.85E-05	8.85E-05
		Bladex 90DF	dry flowable	90	0.9	0	90.00%	10.00%	15%	15.79%	5.67E-04	5.10E-04	0.00E+00	1.59E-05	1.59E-05	1.59E-05
		Fonfos	Lorsban 15G	granular	15					95%	100.00%	3.27E-02	4.91E-03	6.80E-04	5.43E-04	5.43E-04
Dyfonate II 2	granular		20					95%	100.00%	2.45E-02	4.91E-03	0	6.95E-03	6.95E-03	6.95E-03	
Counter (15G)	granular		15					80%	80.00%	2.62E-02	3.93E-03	0	5.56E-03	5.56E-03	5.56E-03	

Counter 20C ? 20 0.2 80.00% 20% 20.00% 4.91E-03 9.81E-04 0 9.81E-04 2.33E-02 lb/bu

Notes: The above table is quite confusing, and I apologize for the convoluted estimation methodology. The complexity is caused by the fact that pesticides are often sold in formulations containing more than one active ingredient. Thus if you treat a 4L pesticide as having 4 lb/gallon of the primary a.i., you will end up double counting the inert portion since the pesticide is actually delivering two forms of a.i. which together sum to 4L. To account for this I added columns in which I calculate the quantity of pesticide used to deliver the appropriate amount of the primary a.i., based on the fraction of each brand used to meet the need for that a.i. These fractions were normalized to 100% to simulate complete coverage by the most important brands cited by Dave Pike. I then estimate the amount of atrazine, the secondary chemical, that comes along for the ride. Finally, I summed up the atrazine from combination forms in the atrazine section, instead of calculating it from the fraction of atrazine applied in various forms. I then modified the fractions for atrazine to try and balance the total atrazine use. This was done by raising the estimated fraction of atrazine use 95.67% of actual use. I then delete the contribution of dual form atrazine formulations from the contribution to the VOC emissions, w 17.17% percent of total pesticide use (by gross pesticide wt.)

VOC emissions are estimated using the data below on the fraction of inert ingredient that are VOC's. These are applied to the total inert ingredient quantities calculated in the above table. Total VOC emissions are then summed. I have included VOC emissions from pesticides in the category non-methane organic compounds, which is a broader class of organics. For a good description of the classification of organics see AP-42 (1995) pages 6 and 7.

I should also note that I made some assumptions about the brands used to supply granular pesticides. Dave Pike did not give brand specific data for these, only the formulation type and strength. In most cases there is only one brand listed of each strength in the data provided by Van Johnson. Thus I used that particular brand data for the pesticide type and strength of interest.

Air Emissions		Surface incorporation fraction estimated based on conversations with Bob Hartzler and Dave Pike.									
Active IngridFrom Table 2		Source: AP-42 Table 9.2.2-1 Source: AP-42 Table 9.2.2-4									
Pesticide	Use Rate	Units	Vapor Pressure	Units	Emission Fac	Surface Applic	Surface Fraction	Total Emissions	Active Ingrid Units	Percent of a.i. Volatilized	
Alachlor	4.01E-03 lb/bu corn	1.4E-05 mm Hg at 20	700	42 lb/ton	70%	1.01E-03 lb/bu	25.13%	70%	1.01E-03 lb/bu	25.13%	
Metholachlor	4.91E-03 lb/bu corn	3.1E-05 mm Hg at 20	700	42 lb/ton	70%	1.23E-03 lb/bu	25.13%	85%	1.86E-03 lb/bu	25.13%	
Atrazine	6.24E-03 lb/bu corn	2.9E-07 mm Hg at 20	700	5.4 lb/ton	85%	1.86E-03 lb/bu	29.79%	85%	9.62E-04 lb/bu	29.79%	
Cyanazine	3.23E-03 lb/bu corn	1.6E-09 mm Hg at 20	700	5.4 lb/ton	100%	2.57E-04 lb/bu	35.00%	100%	1.49E-04 lb/bu	35.00%	
Chlorpyrifos	7.34E-04 lb/bu corn	1.7E-05 mm Hg at 20	700	42 lb/ton	100%	1.49E-04 lb/bu	58.00%	100%	3.95E-04 lb/bu	58.00%	
Fonollos	2.57E-04 lb/bu corn	3.4E-04 mm Hg at 20	1160	104 lb/ton							
Terbufos	6.81E-04 lb/bu corn	3.2E-04 mm Hg at 20	1160	104 lb/ton							

Notes: Estimation method described in AP-42. There is some question of what the application method is for insecticides. They are applied using a planter attachment, and are in granular form. Rod Williamson of the Iowa Corn Growers Association suggests that the granules would thus end up at about the depth of the corn seed, or 1-2 inches. Discussions with Tom Lapp, who developed the section for EPA, suggest that this is not what is referred to as soil incorporated. Instead this is meant to apply to pesticides that are actually injected into the soil. This would more commonly occur with liquid or gaseous forms of pesticides. Accordingly the insecticides are treated as 100% surface application.

Average VOC Content of Pesticide Inert Ingredient Portion (1)

Liquid	20%
Wettable Pow	25%
Microencaps	23%
Dry Flowable	28%
Granule	25%

e (Ali and McBride 1994). This energy Shapouri uses an energy use estimate 980). The exact value of 180,000 btu/lb does not appear comparison of the 1980 estimates reveals put hauling, suggesting at least some double comparative values in Green (1987). Both references formation the more recent estimate is used. This result y use for fertilizer manufacture is difficult to Lorenz appear to rely on estimates has been used in conjunction with data about differ little. The Lorenz values are significantly ng, and application, which would account for much of the difference. focussed on international uses of fertilizers. Since most U.S. timate of energy use for irrigation (18,000 Btu/bu), derived rom 9 mid-western states to estimate on farm energy account for much of the difference in over energy

Emissions by Sector and Type
(lb/lu)

Emission	Cat Tilling (Table 26)	Opera (Table 27)	Nitrogenous Fuel Consum (Table 27)	Process Ammonia (Table 27)	Process Emid Limestone MaProduction (Table 24)	Phosphate R-Farm Fuel Processing Use (Table 34)	Corn Drying (Table 29)	Unallocated Emissions (Table 30)	Urea Manufacture (Table 31)	Ammonium Manufacture (Table 36)	Ammonium Manufacture (Table 37)	Phosphoric Manufacture (Table 38)	Asulfuric Manufacture (Table 40)	Nitric Acid Manufacture (Table 41)	Pesticide Use (Table 42)	Total Emissions	Sum Excluding Nitric Acid MFG	
																	NOx	SOx
NOx	-	3.28E-03	-	3.59E-05	-	0.00161	-	3.65E-02	4.01E-04	0.0008	-	-	-	9.84E-03	-	0.0524	NOx	0.0426
SOx	-	6.37E-06	3.59E-05	-	-	4.73E-06	2.31E-03	2.20E-06	0.0033	0.0003	-	3.41E-05	-	1.46E-02	-	2.03E-02	SOx	PM-10
PM-10	0.348	1.46E-04	-	-	-	1.36E-02	-	4.28E-05	0.0003	-	-	-	-	-	-	3.62E-01	PM-10	CO
CO	-	4.25E-04	0.0099	0.00138	0.00138	2.33E-04	1.41E-01	8.09E-05	0.0002	-	-	-	-	-	-	1.53E-01	CO	CO2
CO2	-	1.28	1.5259	0.29174	0.29174	2.17E-01	2.11E+00	8.76E-01	0.6238	-	-	-	-	-	-	6.93E+00	CO2	Non-Methane
Non-Methane	-	1.50E-05	0	-	-	-	-	2.56E-05	0.0000	-	-	-	-	-	2.33E-02	2.33E-02	Non-Methane VOC's	Methane
Methane	-	3.07E-06	-	-	-	-	-	7.04E-06	0.0000	-	-	-	-	-	-	1.98E-05	Methane	Particulate
Particulate	-	-	-	-	-	-	3.74E-03	1.24E-06	0.0005	-	-	2.90E-04	-	-	-	4.48E-03	Particulate	Hydrocarbon
Hydrocarbon	-	-	-	-	0.00043	-	9.57E-03	-	-	-	-	-	-	-	-	1.00E-02	Hydrocarbons	Aldehydes
Aldehydes	-	-	-	-	-	-	4.70E-04	-	-	-	-	-	-	-	-	4.70E-04	Aldehydes	Ammonia
Ammonia	-	-	0.0026	-	-	-	-	-	0.00480008	6.71E-03	5.96E-05	-	-	-	-	1.42E-02	Ammonia	Nitric Acid
Nitric Acid	-	-	-	-	-	-	-	-	-	1.97E-04	-	-	-	-	-	1.97E-04	Nitric Acid	Fluoride
Fluoride	-	-	-	-	-	-	-	-	-	-	-	1.70E-05	9.08E-07	-	-	1.79E-05	Fluoride	Acid Mist
Acid Mist	-	-	-	-	-	-	-	-	-	-	-	-	-	1.01E-03	-	1.01E-03	Acid Mist	

h only the

ighting times emission factor

Gas Trucks				Light Duty Diesel				Heavy Diesel Trucks			
	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	NOx
1	0	0	0		0	0	0		0	0	0
2	0.3944	1.7952	0.612		0.0408	0.1632	0.1224		0.34	1.1288	1.5096
3	0.3596	1.6936	0.5568		0.0464	0.1392	0.1044		0.3016	1.0556	1.334
4	0.3168	1.5444	0.4851		0.0396	0.1287	0.099		0.2673	1.188	1.188
5	0.289	1.4025	0.4335		0.034	0.1105	0.085		0.238	0.8925	1.037
6	0.2592	1.2744	0.3888		0.036	0.1008	0.072		0.2088	0.7992	0.9
7	0.2294	1.1408	0.341		0.031	0.0868	0.0682		0.186	0.7192	0.7874
8	0.2014	1.0123	0.2968		0.0265	0.0742	0.0583		0.1643	0.6413	0.6837
9	0.1755	0.8865	0.2565		0.0225	0.0675	0.0495		0.144	0.5625	0.5895
10	0.1824	1.5808	0.1976		0.0228	0.057	0.0418		0.1254	0.5016	0.6802
11	0.1716	1.6566	0.1716		0.0198	0.0495	0.0396		0.132	0.4521	0.6006
12	0.3584	4.4296	0.1568		0.0168	0.0448	0.0448		0.1568	0.4144	0.5292
13	0.312	3.8496	0.1344		0.0144	0.0384	0.0384		0.1368	0.3624	0.4536
14	0.262	3.304	0.114		0.012	0.032	0.034		0.116	0.308	0.378
15	0.2376	3.0204	0.1026		0.0126	0.0306	0.0306		0.1206	0.3042	0.369
16	0.207	2.7375	0.0915		0.0105	0.0255	0.0285		0.102	0.258	0.3075
17	0.1807	2.4024	0.0793		0.0182	0.0312	0.0247		0.0949	0.2626	0.3224
18	0.2013	2.3221	0.0704		0.0154	0.0275	0.022		0.0814	0.2255	0.2728
19	0.1782	2.1717	0.0657		0.0135	0.0225	0.018		0.0675	0.1863	0.2232
20	0.8955	10.9485	0.333		0.0675	0.1125	0.09		0.3375	0.9405	1.116
	5.412	49.1729	4.8874		0.5003	1.3424	1.0712		3.3209	10.9948	13.2817

4.91E-04

10.40%

ector

Tilling Opera (Table 26)	Nitrogenous Process EnidLimestone (Table 27) (Table 35)		Phosphate RFArm Fuel Processing Use (Table 34)	Corn Drying (Table 30)	Unallocated Urea Emissions (Table 31)		Ammonium Manufacture Manufacture (Table 36) (Table 37)		Phosphoric ASulfuric Acid Nitric Acid (Table 40) (Table 41)		Pesticide Manufacture Manufacture Use (Table 39) (Table 42)	Total Emissions
	(Table 27)	(Table 35)	(Table 34)	(Table 30)	(Table 31)	(Table 31)	(Table 36)	(Table 37)	(Table 40)	(Table 41)	(Table 39)	
-	8%	0%	4%	86%	1%	2%	-	-	-	-	-	100% NOx
-	0%	0%	0%	11%	0%	16%	-	-	-	72%	-	100% SOx
96%	0%	-	4%	-	0%	0%	-	-	-	-	-	100% PM-10
-	0%	6%	1%	92%	0%	0%	-	-	-	-	-	100% CO
-	18%	22%	4%	30%	13%	9%	-	-	-	-	-	100% CO2
-	0%	0%	-	-	0%	0%	-	-	-	-	-	100% Non-Methane VOC's
-	16%	-	-	-	36%	49%	-	-	-	-	-	100% Methane
-	-	-	-	83%	0%	10%	-	-	-	-	-	100% Particulate
-	-	-	-	96%	-	-	-	-	-	-	-	100% Hydrocarbons
-	-	-	4%	100%	-	-	-	-	-	-	-	100% Aldehydes
-	-	18%	-	-	-	-	34%	47%	-	-	-	100% Ammonia
-	-	-	-	-	-	-	100%	-	-	-	-	100% Nitric Acid
-	-	-	-	-	-	-	-	-	5%	-	-	100% Fluoride
-	-	-	-	-	-	-	-	-	-	100%	-	100% Acid Mist

Sheet Title:

Corn Transportation and Storage

Last Modified

10/03/95

Sheet Description:

This sheet includes the life-cycle inventory components for the transport of corn from the producer to a refining facility, including intermediate storage and processing common with corn. Contrary to some literature assumptions about the primary mode of transport, because of the large volumes of corn consumed at typical facilities, the primary mode is rail. Corn is also most commonly shipped to a grain elevator for storage before shipping to the mill. At the grain elevator several processing operations are carried out. The impact of these operations is included here.

References/Citations:

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List of Tables

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4	Energy Intensity of Corn Transportation Modes
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6	Emissions from Train Transport
7	Emissions from Truck Transportation
8	Emissions from Tractor Transport
9	Fumigant and Grain Protectant Use in Grain Storage
10	Particulate Emissions from Uncontrolled Grain Elevators

Summary Output:

Allocated LCI components

Air

Notes:

DOI

Quantity

Units

Particulates	lb/bu	2.41E-01	3 Dominated by grain handling, emission factor quality average.
SOx	lb/bu	4.33E-04	3 Based on old emission factor data.
CO	lb/bu	2.37E-03	3 Based on old emission factor data.
CO2	lb/bu	4.70E-01	3 Based on old emission factor data.
Hydrocarbons	lb/bu	1.03E-03	3 Based on old emission factor data.
NOx	lb/bu	4.49E-03	3 Based on old emission factor data.
Aldehydes	lb/bu	6.70E-05	3 Based on old emission factor data.
Organic Acids	lb/bu	4.25E-05	3 From train transport. Old data but quality rating good.

Table 6

Particulates	1.52E-04
SOx	3.46E-04
CO	7.89E-04
CO2	1.36E-01
Hydrocarbons	5.70E-04
NOx	2.24E-03
Aldehydes	3.34E-05
Organic Acids	4.25E-05

Train Transport

Conversion Factors

Unit from	Unit to	Multiplier	Name	Source:	Notes:
Gallons Ethanol	Btu		84,600 btu/gallon		5
Gallon Ethanol	lb		6.58 lb/gallon		25 Specific Gravity = .7893
Gallon Ethanol	bu		0.4 bu/gallon		6 Depending on plant and process may range from .385 to .40.
Btu	Joules		1,055 Joules/btu		11
kg	lb		2.20 lb/kg		11
bu	lb		56 lb/bu		11
kcal	btu		3,968 btu/kcal		11
sq. miles	acres		640 acres/sqmile		11
short tons	lb		2,000 lb/shortton		11
Barrels	gallons		42 gallons_barrel		19
Gallon Gasoline	btu		125,071 btu/gallongas		19
Gallon Diesel	btu		138,690 btu/gallondias		19
Cubic Feet N.G.	btu		1,031 btu/cubict		19

Molecular Wts.

Element/Compound	Name	Wt.	Defined Name
C	Carbon	12.01	
O	Oxygen	16.00	
CO2	Carbon Dioxide	44.01	
Ratio CO2/C		3.66	carbon_ratio

Calculations

Table 1 Energy Use in Transportation: Estimates as cited in DeLuchi (1993)

DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

Transformed
Std. Dev.Transformed
Quan.Transformed
Units

DQI

Raw/
Input Std. Dev.Raw/
Input Quan.Raw/
Input Units

Reference

LCI component

Blu/bu
Blu/bu
Blu/bu
Blu/bu
Blu/bu
Blu/bu

12,690
19,035
21,150
14,805
6,345

Giampetro and Pimentel
Chambers et al. (1979)
Paris (1983)
Pimentel (1990)
DeLuchi (1993)

Blu/Btu-ethanol
Blu/Btu-ethanol
Blu/Btu-ethanol
Blu/Btu-ethanol
Blu/Btu-ethanol

0.06
0.09
0.1
0.07
0.03

Transportation
Energy Use

Notes: DeLuchi states in Table K-7 that all data are referenced to the higher heating value of ethanol, and gives transportation energy consumption estimates as a function of blu/btu ethanol. I transform these estimates to blu/bu, then give the values as they appear in the actual reference for those references which I have below.

Calculations

Table 2 Energy Use in Transportation Estimates

Paris, Frederico. 1983. Energy Balances or Ethanol as a Fuel, Advances in Biochemical Engineering/Biotechnology, 28:42-68 (1983).

Pimentel, David et al. 1988. Food Versus Biomass Fuel: Socioeconomic and Environmental Impacts in the United States, Brazil, India, and Kenya, Advances in Food Research, Vol. 32, pp. 185-238, 1988.

Chambers, R.S., et al. 1979. Gasohol: Does It or Doesn't It Produce Positive Net Energy. Science, vol. 206, November 1979, pp. 789-795.

DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, AN/ESD/TM-22, Vol. 2.

Unnasch, Stefan. 1990. Greenhouse Gas Emissions from Ethanol Production and Vehicle Use, Acurex Corp. for the National Corn Growers Association.

LCI component

Raw/
Input UnitsRaw/
Input Quan.Transformed
UnitsTransformed
Quan.Energy to Transport
Corn to Mill

kcal/2700 kg
Blu/bu
MJ/kg ethanol
MJ/kg ethanol
Blu/lb
Blu/bu

325,000
21,000
2.93
0.45
5,600
4,000

Blu/bu
Blu/bu
Blu/bu
Blu/bu
Blu/bu
Blu/bu

12,132
21,000
20,727
3,183
5,600
4,000

Average of Scheller, Pimentel, DeLuchi, Unnasch, and Chambers Estimates.
Standard Deviation

7,484

Notes:

Pimentel et al. (1988). Estimated as 10% of the
Chambers et al. (1979) cites ACR (1978) (unp
Paris cites Chambers (1979)
Paris cites Scheller (1978)
DeLuchi (1993) calculated based on truck Iran
Unnasch (1990)

Notes: The variability in literature estimates of energy use in corn transportation is high. The value arrived at in the calculation below is also much smaller than these estimates
2,920 blu/lb. Since most of the above estimates were made using crude
assumptions, this value is used.

Table 3 Iowa Corn Transportation Statistics

(1) Iowa Department of Agriculture and Land Stewardship. 1991. Grain Marketing: Iowa, Iowa Department of Agriculture.

(2) Baumel, C. Philip, Charles R. Hurburgh, and Terpaio Lee. 1985. Estimates of Total Fuel Consumption in Transporting Grain from Iowa to Major Grain Importing Countries by Alternative Modes and Routes: Special Report 90, Iowa Agricultural and Home Economics Experiment Station, Iowa University of Science and Technology, Ames, Iowa.

(3) Baumel, C. Philip, Stephen Baumhoffer, Michael A. Lipsman, and Marty J. McVey. 1991. Alternative Investments in the Rural Branch Railroad and County Road Systems, Midwest Transportation Center, Iowa State University, Ames, Iowa.

(4) Baumel, C. Philip. unpublished data. Iowa State University, Ames, Iowa.

Grain Merchandised by Elevators/Grain Dealers (1)
Domestic Processing

Method Shipped
Truck
Rail
Barge

38.1%
58
61.7%
281 ND

0.2%

Percent of Bushels
Average Distance (miles)

Grain Shipped by Farmers to Country Elevators (3)

Vehicle Type	Percent	Average 1-way Distance
Semi tractor-trailer	32%	8
Tandem axle truck	29%	13.5
Single axle truck	9%	9.3
Tractor - one wagon	20%	6.3
Tractor - two wagons	10%	6.3

Grain Shipped Directly from Farm to Processor

Source:
Percent of total grain processed

20% (4)

Vehicle Type	Percent	Average Distance	Notes:
Tandem Axle	5%	58	Assumed to be the same as average distance from elevator to farmer
Semi	95%	58	Assumed to be the same as average distance from elevator to farmer

Notes: According to this model, 80% of corn processed domestically is shipped first to an elevator, then to the processor. The remaining 20% is shipped straight from farm to processor, which includes some corn sold to the elevator but transported directly to the processor.

Table 4 Energy Intensity of Corn Transportation Modes

(1) Baumel, C. Philip, Charles R. Hurburgh, and Tenpao Lee. 1985. Estimates of Total Fuel Consumption in Transporting Grain from Iowa to Major Grain Importing Countries by Alternative Modes and Routes: Special Report 90, Iowa Agricultural and Home Economics Experiment Station, Iowa University of Science and Technology, Ames, Iowa.

(2) Baumel, C. Philip, Stephen Baumhover, Michael A. Lipsman, and Marty J. McVey. 1991. Alternative Investments in the Rural Branch Railroad and County Road Systems, Midwest Transportation Center, Iowa State University, Ames, Iowa.

(3) Baumel, C. Philip, unpublished data, Iowa State University, Ames, Iowa.

Energy Intensity of Corn Transportation Modes

Mode	Intensity	Units	Source:	Fuel	Transformed Intensity	Units	Capacity	Units
Rail	640.1	Net Ton-mi/gallon	(1)	Diesel	22,861	Net Bu-mi/gallon		
Semi trucks	90.5	Net Ton-mi/gallon	(1)	Diesel	3,232	Net Bu-mi/gallon		53,200 lb
Tandem axle trucks	37.8	Net Ton-mi/gallon	(2)	Diesel	1,350	Net Bu-mi/gallon		33,600 lb
Single axle trucks	30.2	Net Ton-mi/gallon	(2)	Gasoline	1,079	Net Bu-mi/gallon		16,800 lb
Tractor - 1-300 bushel wagon	12.6	Net Ton-mi/gallon	(3)	Diesel	450	Net Bu-mi/gallon		16,800 lb
Tractor - 2-300 bushel wagons	25.2	Net Ton-mi/gallon	(3)	Diesel	900	Net Bu-mi/gallon		33,600 lb

Notes: Energy intensity estimates in terms of net ton-miles per gallon account for the actual tonnage hauled and the distance traveled unloaded (backhaul). Thus bushel-miles per gallon cannot be used to calculate a real mileage, since they include unloaded miles.

Table 5 Derived Total Transportation Requirements for Corn

From Table 3

Mode	Distance (1-way)	Units	Energy	Units
Railroad	138.70	Miles	841.5	Bu/bu
Semi tractor-trailer	28.70	Miles	1,231.4	Bu/bu
Tandem axle truck	3.71	Miles	381.3	Bu/bu
Single axle truck	0.67	Miles	77.6	Bu/bu
Tractor - one wagon	1.01	Miles	310.7	Bu/bu
Tractor - two wagons	0.50	Miles	77.7	Bu/bu
Total			2,920.2	Bu/bu

Notes: In this table, the transportation modes, distances, intensity, and fractions have been used to generate what could be called the average bushel transportation requirements. This does not imply that any single bushel actually travels the above distances for each mode. Instead it is a way

of representing the average requirements to transport corn.

Table 6
Emissions from Train Transport

- (1) U.S. EPA, AP-42, Table II-2.1 (1985)
- (2) U.S. DOE/EIA, 1994, Annual Energy Review: 1993, DOE/EIA-0384(93).
- (3) DOE/EIA, 1994, Emissions of Greenhouse Gases in the United States: 1987-1992, DOE/EIA-0573

Energy Intensity	841 Btu/bu 0.0061 Gallons/bu	From Table Above			
Emission Factors - Railway	Raw Input Quantity	Units	Source	Transformed Quantity	Units
Particulates	25 lb/1000 gal fuel	(1)		0.18 lb/million bu	
SOx	57 lb/1000 gal fuel	(1)		0.41 lb/million bu	
CO	130 lb/1000 gal fuel	(1)		0.94 lb/million bu	
CO2	19.95 kg/million bu	(4)		161.16 lb/million bu	
Hydrocarbons	94 lb/1000 gal fuel	(1)		0.88 lb/million bu	
NOx	370 lb/1000 gal fuel	(1)		2.67 lb/million bu	
Aldehydes	5.5 lb/1000 gal fuel	(1)		0.04 lb/million bu	
Organic Acids	7 lb/1000 gal fuel	(1)		0.05 lb/million bu	

Emissions	Quantity	Units
Particulates	1.52E-04	lb/bu
SOx	3.46E-04	lb/bu
CO	7.89E-04	lb/bu
CO2	1.36E-01	lb/bu
Hydrocarbons	5.70E-04	lb/bu
NOx	2.24E-03	lb/bu
Aldehydes	3.34E-05	lb/bu
Organic Acids	4.25E-05	lb/bu

Table 7
Emissions from Truck Transportation

- (1) Davis, Stacy C. 1994. Transportation Energy Data Book: Edition 14. Oak Ridge National Laboratory, ORNL-6798.
- (2) DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.
- (3) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.
- (4) U.S. DOE/EIA, 1994, Annual Energy Review: 1993, DOE/EIA-0384(93).
- (5) United States Environmental Protection Agency, 1985. Compilation of Air Pollutant Emission Factors, AP-42 Fourth Edition.

Estimated Transport Distance	Distance	Units	Energy	Units
Semi	28.70	Miles	1,231.44	Btu/bu
Tandem Axle	3.71	Miles	381.35	Btu/bu
Single Axle	0.67	Miles	77.65	Btu/bu
Estimated Vehicle Load				
Semi	53,200	lb		
Tandem Axle	33,600	lb		
Single Axle	16,800	lb		

Notes:
Data provided by Philip Baunel
Data provided by Philip Baunel
Data provided by Philip Baunel

Vehicle Registration Mix: January 1 & emissions factors, g/mile (5)

Model Year	Gas Trucks				Light Duty Diesel				Heavy Diesel Trucks			
	Fraction	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	
Model Year - 1	0	0	2.8	12.6	4.4	0.008	0.3	1.2	0.9	0.031	2.4	7.9
Model Year - 2	0.136	0.136	2.9	13.2	4.5	0.006	0.3	1.2	0.9	0.007	2.5	8.3
Model Year - 3	0.116	0.116	3.1	14.6	4.8	0.008	0.4	1.2	0.9	0.008	2.6	9.1
Model Year - 4	0.099	0.099	3.2	15.6	4.9	0.011	0.4	1.3	1	0.01	2.7	9.9
Model Year - 5	0.085	0.085	3.4	16.5	5.1	0.017	0.4	1.3	1	0.012	2.8	10.5
Model Year - 6	0.072	0.072	3.6	17.7	5.4	0.023	0.5	1.4	1	0.014	2.9	11.1
Model Year - 7	0.062	0.062	3.7	18.4	5.5	0.029	0.5	1.4	1.1	0.017	3	11.6
Model Year - 8	0.053	0.053	3.8	19.1	5.6	0.035	0.5	1.4	1.1	0.021	3.1	12.1
Model Year - 9	0.045	0.045	3.9	19.7	5.7	0.041	0.5	1.5	1.1	0.025	3.2	12.5
Model Year - 10	0.038	0.038	4.8	41.6	5.2	0.047	0.6	1.5	1.1	0.03	3.3	13.2
Model Year - 11	0.028	0.028	5.2	50.2	5.6	0.059	0.6	1.5	1.2	0.036	4	13.7
Model Year - 12	0.024	0.024	13	160.4	5.6	0.065	0.6	1.6	1.6	0.043	5.6	14.8
Model Year - 13	0.02	0.02	13.1	165.2	5.7	0.071	0.6	1.6	1.6	0.051	5.7	15.1
Model Year - 14	0.018	0.018	13.2	167.8	6.1	0.083	0.7	1.7	1.7	0.061	5.8	15.4
Model Year - 15	0.015	0.015	13.8	182.5	6.1	0.089	1.4	2.4	1.9	0.068	6.7	16.9
Model Year - 16	0.013	0.013	13.9	184.8	6.1	0.095	1.4	2.4	1.9	0.105	7.3	17.2
Model Year - 17	0.011	0.011	18.3	211.1	6.4	0.101	1.5	2.5	2	0.126	7.4	20.5
Model Year - 18	0.009	0.009	19.8	241.3	7.3	0.107	1.5	2.5	2	0.151	7.5	20.7
Model Year - 19	0.045	0.045	19.9	243.3	7.4	0.027	1.5	2.5	2	0	7.5	20.9
Model Year - 20	92.20%	92.20%	5.9	53.3	5.3	94.50%	0.5	1.4	1.1	90.90%	3.7	12.1

Transformed Input Quantity Units

Emission Factors	Raw Input Quantity	Units
Gas Truck		
Hydrocarbons	5.9 g/mile	0.0129 lb/mi
Carbon Monoxide	53.3 g/mile	0.1176 lb/mi
NOx	5.3 g/mile	0.0117 lb/mi
Light Diesel Truck		
Hydrocarbons	0.5 g/mile	0.0012 lb/mi
Carbon Monoxide	1.4 g/mile	0.0031 lb/mi
NOx	1.1 g/mile	0.0025 lb/mi
Heavy Diesel Truck		
Hydrocarbons	3.7 g/mile	0.0081 lb/mi
Carbon Monoxide	12.1 g/mile	0.0267 lb/mi
NOx	14.6 g/mile	0.0322 lb/mi
CO2 Emission Factors		
Gas	19.4 kg/million bu	156.79 lb/million bu
Diesel	20.0 kg/million bu	161.16 lb/million bu

Transformed Input Quantity Units

Emissions	Heavy Diesel	Gas	Total
Hydrocarbons	0.00024	7.22087E-06	2.88439E-05
Carbon Monoxide	0.00081	1.9375E-05	0.000279415
NOx	0.00097	1.54607E-05	0.00108736
CO2	0.19845	0.061456568	0.012174601

Notes: The three categories of trucks used in corn transportation were arbitrarily assigned to the three categories of trucks for which emissions factors are available in AP-42. There is some danger in this since the AP-42 emission factors are given in terms of g/mi. Clearly the size assumptions about the truck categories in AP-42 would have a significant impact on the emission factors in terms of g/mi. Closer examination of AP-42 reveals that the light truck category refers to vehicles with gross weights between 6,000 and 8,500 lbs. This suggests that the BMI load estimate of 10,000 lb is high. Unfortunately the resolution of the AP-42 data is poor. The category large trucks includes all vehicles over 8,500 lbs. Thus, while the large vehicle capacity of 42,000 lb is confirmed as being reasonable for trucks used to haul corn, this would seem to fall at the high end of the large truck category in AP-42. Lacking more detailed truck emission factors, these estimates will be used.

Table 8 Emissions from Tractor Transport

(1)	U.S. EPA. 1991. Nonroad Engine and Vehicle Emission Study-Appendix (sp). Draft, 21A-2001 (NTIS #PB92-104462).
(2)	United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the United States: 1987-1992, DOE/EIA-0573
Estimated Energy Usage	
Tractor - one wagon	Energy 311 blt/bu Units
Tractor - two wagons	Fuel 0.00224 Gallons/bu Units

Total		388	bu/bu	0.0028 Gallons/bu											
Farm Equipment Emission Factors Units		Raw Input Quantity													
Diesel Tractors	lb/1000 gallons	HC		CO	63.55	NOx	175	SOx	438.59	Particulate	31.2	Aldehydes	45.7	12 (1)	Notes
Weighted by factors for large 2WD, small 2WD, and 4WD tractors.															
Carbon Dioxide Emission Factor Diesel		Quantity	Units	Source (2)											
			19.95 kg/million bu												
			161.16 lb/million bu												
Emissions		Quantity	Units												
Hydrocarbons		1.78E-04	lb/bu												
CO		4.90E-04	lb/bu												
NOx		1.23E-03	lb/bu												
SOx		8.74E-05	lb/bu												
Particulate		1.28E-04	lb/bu												
Aldehydes		3.36E-05	lb/bu												
CO2		0.06	lb/bu												

Notes: In this table, emission factors for diesel tractors have been used for all tractor transport. While on farm energy consumption estimates suggest that some gasoline is used, it is not possible to determine the amount of gasoline used in tractors. Since some transport is carried out by light trucks, and since some of these trucks may be gas powered, it is assumed here that assigning diesel emission factors to tractor transport is a reasonable approximation. The impact of this assumption is primarily on the carbon monoxide estimates, for which gas tractors have an extremely high emission factor. Lacking additional data, the diesel tractor assumption will be used.

Table 9 Fumigant and Grain Protectant Use in Grain Storage

Personal Communication, C.L. Storey, Consultant on Protection of Stored Grains, July 27, 1995.

United States Department of Agriculture, Office of Pesticide Research. 1987. Biologic and Economic Assessment of Stored Corn, Wheat, and Peanut Fumigants in The Biologic and Economic Assessment of Registered Fumigants, USDA Office of Pesticide Research, Washington, D.C.

Aluminum Phosphide Use: 1987		Total Use		Units	Com Treated	Units	Use Rate	Units
Off Farm		20,790	kg	415.8	million Bushels	1.10E-04	lb/bu	
Percent of Corn Bushels Treated								
20.7%								
Aluminum Phosphide use per Total Bushels								
2.28E-05								
lb/bu								

For many reasons, the use of chemicals to protect stored grain is negligible. Corn carries a lenient standard relative to grains such as wheat, on the number of insects allowed per unit measure before the grain is classified as weevil. About 65-70% of corn also never leaves the region in which it was produced, which limits storage and transportation times, again limiting the need for chemical treatment. Finally, the use of chemical protectants is very small relative to the use of insecticides and herbicides applied in the field.

Though several different types of fumigants were once used with corn, many of these have not been re-registered by the EPA. These include Methyl Bromide, which is an ozone depleting substance, and well as chloropicrin and magnesium phosphide. The only fumigant currently in use in significant quantities is aluminum phosphide. This substance produces a phosphine gas which is toxic to both insects and humans, and is suspected of causing genetic abnormalities in cell tissue. Charles Storey estimates that less than 10% of corn is fumigated. Of grain protectants, acetic (parmitos methyl) is the only important one used on corn. Again, the use of this substance is estimated to be very small.

Table 10 Particulate Emissions from Uncontrolled Grain Elevators

U.S. EPA. 1985. AP-42 Compilation of Air Pollutant Emission Factors, 4th Edition Chapter 6.4-1.

Emission Factors	Process	Quantity	Units
Country Elevators	Unloading	0.6	lb/ton

Inland Terminal Elevators	Loading	0.4 lb/ton	Transformed Quantity Units 0.2408 lb/bu
	Removal From Bins	2 lb/ton	
	Drying	0.2 lb/ton	
	Cleaning	0.4 lb/ton	
	Headhouse	5 lb/ton	
	Total	8.6 lb/ton	
	Unloading	1 lb/ton	
	Loading	0.4 lb/ton	
	Removal From Bins	2.8 lb/ton	
	Drying	0.2 lb/ton	
Average	Cleaning	0.6 lb/ton	Transformed Quantity Units 0.2772 lb/bu
	Headhouse	4.6 lb/ton	
	Tripper (Gallery Belt)	1.6 lb/ton	
	Total	11.2 lb/ton	
		9.9 lb/ton	

Notes: These emission factors account for the quantity of grain processed by each operation per unit of grain shipped. This ranges from as low as 0.1 to as high as 3.1. These data indicate that about 30% of grain received at country elevators is dried at the elevator compared to 10% of received grain being dried at inland terminal elevators. Since corn bound for domestic processing usually passes only through country elevators, the emission factors for country elevators are used. It is assumed that all energy use for drying is accounted for in the corn production sheet.

Table 7 Truck Transport	Table 8 Tractor Transport	Table 12 Grain Handling	Total					
				Table 6 Train Transport	Table 7 Truck Transport	Table 8 Tractor Transport	Table 12 Grain Handling	Total
-	-	1.28E-04	0.24108	0%	#VALUE!	0%	0%	100%
-	1.09E-03	8.74E-05	0.000433	80%	#VALUE!	20%	#VALUE!	100%
-	2.72E-01	4.90E-04	0.002366	33%	46%	21%	#VALUE!	100%
2.79E-04	6.26E-02	-	0.470276	29%	58%	13%	#VALUE!	100%
1.01E-03	1.78E-04	-	0.001028	55%	27%	17%	#VALUE!	100%
-	1.23E-03	-	0.004488	50%	23%	27%	#VALUE!	100%
-	3.36E-05	-	6.7E-05	50%	#VALUE!	50%	#VALUE!	100%
-	-	-	4.25E-05	100%	#VALUE!	#VALUE!	#VALUE!	100%

Particulates
SOx
CO
CO2
Hydrocarbons
NOx
Aldehydes
Organic Acids

e energy input to corn production, including energy in fertilizers, etc.
ublished).

sport 80 miles roundtrip plus occasional train transport bringing total energy to 200,000 Btu/ton.

Transformed Intensity	Units
6.1	Bu/Bu-mile
42.9	Bu/Bu-mile
102.7	Bu/Bu-mile
116.0	Bu/Bu-mile
308.2	Bu/Bu-mile
154.1	Bu/Bu-mile

Product of weighting times emission factor

NOx		Gas Trucks			Light Duty Diesel			Heavy Diesel Trucks		
		Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	Fraction	Total HydroCO	NOx
11	Model Year -1	0	0	0	0	0	0	0	0	0
11.1	Model Year -2	0.3944	1.7952	0.612	0.5668	0.0408	0.1632	0.1224	0.34	1.1288
11.5	Model Year -3	0.3996	1.6936	0.5968	0.4851	0.0464	0.1392	0.1044	0.3016	1.0556
12	Model Year -4	0.3168	1.5444	0.4851	0.4335	0.0396	0.1287	0.099	0.2673	0.9801
12.2	Model Year -5	0.289	1.4025	0.4335	0.3888	0.034	0.1105	0.085	0.238	0.8925
12.5	Model Year -6	0.2592	1.2744	0.3888	0.341	0.036	0.1008	0.072	0.2088	0.7992
12.7	Model Year -7	0.2294	1.1408	0.341	0.2968	0.031	0.0868	0.0682	0.186	0.7192
12.9	Model Year -8	0.2014	1.0123	0.2968	0.2565	0.0265	0.0742	0.0583	0.1643	0.6413
13.1	Model Year -9	0.1755	0.8865	0.2565	0.1976	0.0225	0.0675	0.0495	0.144	0.5625
17.9	Model Year -10	0.1824	1.5808	0.1976	0.1568	0.0228	0.057	0.0418	0.1254	0.5016
18.2	Model Year -11	0.1716	1.5566	0.1716	0.1344	0.0198	0.0495	0.0396	0.132	0.4521
18.9	Model Year -12	0.3584	4.4296	0.1568	0.114	0.0168	0.0448	0.0448	0.1568	0.4144
18.9	Model Year -13	0.312	3.8496	0.114	0.1026	0.0144	0.0384	0.0384	0.1368	0.3624
18.9	Model Year -14	0.262	3.304	0.1026	0.0915	0.012	0.032	0.034	0.116	0.308
20.5	Model Year -15	0.2376	3.0204	0.0915	0.0793	0.0126	0.0306	0.0306	0.1206	0.3042
20.5	Model Year -16	0.207	2.7375	0.0793	0.0704	0.0105	0.0255	0.0285	0.102	0.258
24.8	Model Year -17	0.1807	2.4024	0.0704	0.0657	0.0182	0.0312	0.0247	0.0949	0.2626
24.8	Model Year -18	0.2013	2.3221	0.0657	0.0333	0.0154	0.0275	0.022	0.0814	0.2255
24.8	Model Year -19	0.1782	2.1717	0.0333	0.0333	0.0135	0.0225	0.018	0.0675	0.1863
24.8	Model Year -20	0.8955	10.9485	0.333	4.8874	0.0575	0.1125	0.09	0.3375	0.9405
14.6	sum	5.412	49.1729	4.8874		0.5003	1.3424	1.0712	3.3209	10.9948
										13.2817

Sheet Title: Corn Wet Milling Last Modified 10/04/95

Sheet Description:

This sheet contains an inventory of the wet corn milling process. The process inputs and outputs are normalized to one bushel of corn input. Energy intensity estimates for wet corn milling are derived from 1991 MECS data for SIC 2046. This industry includes manufacturers of wheat, potato, and tapioca starch, as well as corn starch and other corn wet milling products. Though the industry has relatively high coverage (95) and specialization (88) ratios (U.S. Department of Commerce 1994), the industry does produce significant quantities of ethanol, a relatively energy intensive product. Most public literature on material consumption by the industry separates out materials used for ethanol production. Energy use estimates contained in MECS do not make this distinction, however. In order to use the MECS data it is necessary to allocate some fraction of energy consumption to the production of potato, wheat, and tapioca starch, as well as ethanol production. The first two tables in this sheet deal with the allocation of energy consumption to these products. Table 3 then uses the adjusted MECS data to develop an energy balance for the wet corn milling industry.

There are also several co-products of glucose (or corn starch, depending on the desired end product). These include corn oil and animal feeds. Inputs and outputs of the industry must be allocated between these products. This has been done on this sheet on the basis of product dry weight. Thus the right hand column gives the inputs and outputs per pound of product output, which can be applied to any of the products and coproducts.

Some data was derived in these estimates from publicly available databases. Because these datasets are fairly large, they have been included on separate sheets of the file. Sheet two contains the raw TRI data. Sheet three contains power plant coal ash content data. Sheet 4 contains power plant sulfur content data.

NREL has developed a process model for a wet corn mill to provide glucose for the BDO process. The starch conversion component of this model was only recently completed, and so while the results are often included here for comparison purposes, insufficient time was available to reconcile differences. Some of these are fairly significant. For example energy use in the NREL model is only about half that estimated based on public data. The estimates based on public data are crude enough to suggest that this discrepancy may be an overestimate. Again, the time frame for completion of the module limit our ability to further explore the source of these differences.

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List of Tables:

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- 1 Ethanol Production: 1991
- 2 Production of Potato and Wheat Starch in SIC 2046
- 3 Wet Corn Mill Energy Balance
- 4 Electricity Balance in Wet Corn Milling Industry
- 5 Emissions from Energy Consumption in Wet Corn Mills
- 6 Toxic Releases from The Wet Corn Milling Industry
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- 9 Water Consumption in Wet Corn Mills
- 10 Material Balance in Wet Corn Mills
- 11 Sulfur Dioxide Use in Wet Corn Milling Industry
- 12 Ash Production from Coal Consumption

Summary Output:

Allocated LCI components		Units	Unallocated Quantity	Units	Allocated Quantity	Data Quality Indicator	Comments
Air	NOX	lb/bu	0.048	lb/lb product	9.72E-04		2 Driven by AP-42 data on fluidized bed coal combustion, data qu
	SOx	lb/bu	0.052	lb/lb product	1.08E-03		2 Driven by AP-42 data on fluidized bed coal combustion, data qu
	PM-10	lb/bu	0.032	lb/lb product	6.41E-04		2 Driven by AP-42 data on fluidized bed coal combustion, data qu
	Total Particulate	lb/bu	0.086	lb/lb product	1.74E-03		2 Large variations in uncontrolled and controlled values.
	CO	lb/bu	0.044	lb/lb product	8.91E-04		2 Driven by AP-42 data on fluidized bed coal combustion, data qu
	CO2	lb/bu	15.62	lb/lb product	3.18E-01		2 Driven by AP-42 data on fluidized bed coal combustion, data qu
	Non-Methane Org. Comb	lb/bu	1.73E-04	lb/lb product	3.51E-06		2 Driven by AP-42 data on fluidized bed coal combustion, data qu
	Methane	lb/bu	1.52E-04	lb/lb product	3.09E-06		2 Driven by AP-42 data on fluidized bed coal combustion, data qu
	N2O	lb/bu	0.013	lb/lb product	2.72E-04		2 Driven by AP-42 data on fluidized bed coal combustion, data qu
	HCL	lb/bu	3.57E-04	lb/lb product	7.26E-06		3 Based on aggregate TRI data for several years.
	Ammonia	lb/bu	8.85E-05	lb/lb product	1.80E-06		3 Based on aggregate TRI data for several years.
	Chlorine	lb/bu	3.91E-05	lb/lb product	7.95E-07		3 Based on aggregate TRI data for several years.
	Sulfuric Acid	lb/bu	2.41E-05	lb/lb product	4.90E-07		3 Based on aggregate TRI data for several years.
	Total Water Emission	gallons/bu	30	gallons/lb product	0.61		3 Typical estimate. No assessment of statistical reliability.
Water	Ammonia	lb/bu	2.80E-04	lb/lb product	5.70E-06		3 Based on aggregate TRI data for several years.
	Chlorine	lb/bu	1.60E-06	lb/lb product	3.26E-08		3 Based on aggregate TRI data for several years.
	BOD5	lb/bu	0.020	lb/lb product	4.07E-04		3 Based on CFR regulations for new Facilities.
	TSS	lb/bu	0.025	lb/lb product	5.09E-04		3 Based on CFR regulations for new Facilities.
Solid Wastes	HCL	lb/bu	5.50E-06	lb/lb product	1.12E-07		3 Based on aggregate TRI data for several years.

Ammonia	lb/bu	9.00E-06	lb/lb product	1.83E-07	3 Based on aggregate TRI data for several years.
Coal Ash	lb/bu	0.64	lb/lb product	1.30E-02	3 Estimated from information on typical mid-west utility coal.
Resource ConsN.G.	Btu/bu	40,479	Btu/lb product	823	2 No current process specific data available. Derived from industr
Coal	Btu/bu	52,255	Btu/lb product	1,063	2 No current process specific data available. Derived from industr
Electricity	Kwh/bu	3.38	Kwh/lb product	0.069	2 No current process specific data available. Derived from industr
Water	gallons/bu	35	Gallons/lb product	0.712	2 Typical estimate. No assessment of statistical reliability.
Sulfur	lb/bu	0.06	lb/lb product	0.0012	3 Modeled estimate conforms with other published estimates.
Total	lb/bu	49.16	Percent	100.00%	4 Material balance based on large sample and current data, and c
Glucose	lb/bu	32.17	Percent	65.45%	4 Material balance based on large sample and current data, and c
Corn Oil	lb/bu	0.95	Percent	1.94%	4 Material balance based on large sample and current data, and c
Gluten Feed	lb/bu	13.60	Percent	27.67%	4 Material balance based on large sample and current data, and c
Gluten Meal	lb/bu	2.43	Percent	4.94%	4 Material balance based on large sample and current data, and c

Conversion Factors

Unit from	Unit to	Multiplier	Name	Source
bu	lb		56 lb_bu	15
Hectares	acre		2.47 acre_ha	15
kg	lb		2.20 lb_kg	15
hectares	sq. meters		10,000 sqmeters_ha	15
meter	feet		3.28 feet_meter	15
short tons	lb		2,000 lb_shortton	15
kcal	btu		3.97 btu_kcal	15
Joules	btu		9.47E-04 btu_joule	15
Gallons Ethano lb			6.58 lb_gallon	34 Specific Gravity = .7893
Gallons Ethano bu			0.4 bu_gallon	11 Depending on plant and process may range from .385 to .40.
Hectares	Sq. cm		1.00E+08 sqcm_ha	15
cubic cm	liters		0.001 liters_cm	15
liters	gallons		0.264 gallons_liter	15
sq mile	acres		640 acres_sqmile	15
metric tons	short tons		1.10 shortton_metricton	15
Gallon Ethanol Btu			84,600 Btu_gallon	10
Gallons	liters		3.7854 liters_gallon	15
Gallons water lb			8.35 lb_gallonw	15
Tons of Coal	Million Btu		22,276,000 btu_toncoal	25

Molecular Wts.	Element/Compound	Name	Wt.	Defined Name
Ca	Calcium	Calcium	40.080	
O	Oxygen	Oxygen	15.999	
S	Sulfur	Sulfur	32.060	
CaSO4	Calcium Sulfate	Calcium Sulfate	96.058	
C	Carbon	Carbon	12.011	

CO2	44.010
Ratio CaSO4:S	4.246 gypsum_ratio
Ratio CO2:Ca	1.098 calcium_ratio
Ratio CO2:S	1.373 sulfur_ratio
Ratio CO2:C	3.66 carbon_ratio
Ratio S:SO2	0.50 sulfioxide_ratio

Carbon Dioxide

Calculation

Table 1 Ethanol Production: 1991

- (1) USDA/ERS:1993. Feed Situation and Outlook Report.
- (2) National Corn Growers Association, and National Corn Development Foundation. 1995. The World of Corn: 1995.
- (3) Data provided by Kathy Bryan, Consultant to Ethanol Industry
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Raw Input Quantity	Units	Source
Corn Grind for A	429 Million Bu	(1)
Ethanol per bu	2.5 Gallons/bu	(2)
Gallons Ethano	1072.5 Million Gallons	(calculated)
% Capacity of C	49.70%	(3)
Estimated Prod	533 Million Gallons	(calculated)
Energy Intensity	49,504 Btu/gallon	(see below)
	1.36 Kwh/gallon	(see below)
Energy Consum	26.39 Trillion Btu	(calculated)
	724 Million Kwh	(calculated)
		49504 Btu/gallon
		4637 Btu/gallon
		26.39 Trillion Btu
		2.47 Trillion Btu

Notes: Corn use data is typically based on the corn marketing year, which, like the DOE fiscal year, begins September 1. I have used the 1990/91

marketing year data to estimate corn grind for alcohol production in 1991.

Estimates of Energy Intensity of Ethanol Production

Raw Input Quantity	Units	Source	Range from	to	Transformed Input Quantity	Units	Range from	to	Units
17.11 MM J/kg 0.32 kwh/liter		(4)	14.11		20.11	48,366 Btu/gallon 4,133 Btu/gallon	39,885		56,846 Btu/gallon
0.525 Btu/Btu Ethanol 0.05 Btu/Btu Ethanol		(5) (electricity)	0.35		0.6	44,415 Btu/gallon 4,230 Btu/gallon	29,610		50,760 Btu/gallon
41,000 Btu/gal 1.50 kwh/gallon		(6)	34,000		48,000	41,000 Btu/gallon 5,118 Btu/gallon	34,000		48,000 Btu/gallon
0.55 Btu/Btu Ethanol 1.26 kwh/gallon		(7)				46,530 Btu/gallon 4,299 Btu/gallon			
16,329 tons coal 7,236,232 kwh 5,400,744 gallons ethanol		(9)				67,351 Btu/gallon 4,572 Btu/gallon			
4,670 tons coal 3,378,600 kwh 2,107,511 gallons ethanol		(9)				49,361 Btu/gallon 5,470 Btu/gallon			
			Average			49,504 Btu/gallon 4,637 Btu/gallon 1.36 kwh/gallon			

Notes:
South Point Ethanol in October 1984

Kentucky Ag. Energy plant in July 1987

Fuel
Electricity
Electricity

Notes: Ethanol energy intensity estimates vary more widely than is indicated by this data. I have tried to use the most recent data available for which both fuel and electricity estimates are given separately. Where possible I have used electricity estimates given in kwh/unit ethanol to avoid errors in converting to btus. I then convert to btus using the convention of 3412 btu/kwh.

Table 2 Production of Potato and Wheat Starch in SIC 2046

(1) CE Power Systems. 1967. Steam Tables: Properties of Saturated and Superheated Steam, reprinted from ASME Steam Tables (1967).

(2) Cengel, Y. A., and M. Boles. 1989. Thermodynamics: An Engineering Approach, McGraw-Hill, Inc., New York.

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(4) Personal Communication, Damon Horn, A.E. Staley, Stanfield, OR.
Personal Communication, Mick Persinger, Penwest, Richland, WA.

Most potato starch plants purchase a slurry from other processing facilities (e.g. A.E. Staley, Stanfield and Murtaugh plants, and Penwest, Richland and Idaho Falls plants). Energy is consumed in motors and dryers. Assuming that the drying energy dominates, we can calculate an energy intensity per lb based on data from A.E. Staley, Stanfield.

	Raw Input Quantity	Units	Source	Notes:
Purchased Slurry				
Slurry Density		22 Baume	(4)	Damon Horn provided me with detailed estimates of the operating parameters of a mill which dries purchases s
Approximate Solids		36%	(4)	
Centrifuge to Cake Moisture		42.00%	(4)	
Dry to Final Moisture		12.50%	(4)	
Dryer Operation				
Input				
Water		63,362 lb/day	(calculated)	
Starch		87,500 lb/day	(calculated)	
Total		150,862 lb/day	(calculated)	
Output				
Water		12,500 lb/day	(calculated)	
Starch		87,500 lb/day	(calculated)	
Total		100,000 lb/day	(4)	
Dryer Removes Water		50,862 lb/day	(calculated)	
Enthalpy of Vaporization at 212 F		970.30 Btu/lb	(1)	
Specific Heat of Water		1 Btu/lF	(2)	
Temp in		70 F	(estimate)	
Temp out		212 F	(estimate)	
Energy to dry starch		1,112 Btu/lb water evaporate	(calculated)	This estimate was carried out as a check on the other method. While 90% efficiency may be a little high for a starch dryer, for the level of accuracy needed here this provides and acceptable concurrence to the above energy intensity estimate.
Total Energy		56,573,879 Btu	(calculated)	
Intensity		566 Btu/lb dry starch	(calculated)	
Dryer Rating		7 million Btu/hr	(4)	
Capacity		60%	(4)	
Effective Input		4.2 million Btu/hr	(calculated)	
Daily Operation		15 hours	(4)	
Output		100,000 lb	(4)	
Total Energy/lb		630 Btu/lb	(calculated)	
Efficiency		89.8%	(calculated)	
Potato Starch Production 1992				
Energy Use		0.207 Billion lb	(3)	

Estimate Wheat Starch Energy Intensity from Potato		
Wheat Starch Production 1992	1.30E+11 Btu 0.130 T Btu	(calculated) (calculated)
Energy Use	0.276 Billion lb	(3)
Same for Tapioca		
Tapioca Starch Production 1992	1.74E+11 Btu 0.174 T Btu	(calculated) (calculated)
Energy Use	0.069 Billion lb	(3)
	4.35E+10 Btu 0.043 T Btu	(calculated) (calculated)
Total Potato, Wheat, and Tapioca Starch Energy	0.348 T Btu	(calculated)

Notes: Based on these estimates the total energy use for starch drying is quite small. Assuming that there is additional electrical energy consumption, and that some facilities produce potato starch from potatoes instead of a slurry, the total energy consumption may be as much as double this value, which is still negligible relative to total energy use in SIC 2046.

Table 3 Wet Corn Mill Energy Balance

- (1) Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).
- (2) USDA/ERS. 1994. Sugar and Sweetener: Situation and Outlook Report, SSSV 19N2, June 1994.
- (3) Divine, T.E., D.P. Alzheimer, and W.F. Smith. 1977. Estimates of Process Energy Use in Four Key Food Products Industries, presented at the 1977 Annual Meeting of the Pacific Northwest Region American Society of Agricultural Engineers, Pendleton, OR, September 7-9, 1977.

Notes: Based on 1991 MECS energy consumption for all purposes. Electricity data is taken from Table 4. Energy use is rounded to eliminate minor fuels, then adjusted to account for energy use in ethanol production.

1991 Corn Grin	811 MM Bu	(2)
Total Primary Consumption of Fuel for All Purposes (MECS Table 1) (Trillion Btu)		
Fuel	Raw Input Quantity	Rounded Input Quantity
	Less Ethanol Energy	Adj. Total
		Energy per Bushel (Btu)

R. Oil	0.18	0	0	0	0
D. Oil	0.17	0	0	0	0
N.G.	52	55	12	43	53,615
LPG	0.004	0	0	0	0
Coal	68	71	15	56	69,212
Coke, Breeze and Other	6	0	0	0	0
Electricity					
Purchased	14	14	2	12	15,293
Sold	0	0	0	0	0
Conv. Gen.	6	6	1	5	6,519
Renew. Gen.	0	0	0	0	0
Net Fuel	126	126	26	100	122,827
Net Electric	20	20	2	18	21,812

Energy Intensity of Production - SIC 2046

Energy Consumed			100 Tbtu	
Grind			811 MM bushels	
Fuel Energy Intensity			122,827 Btu/bu	2,193 Btu/lb
Electric Energy Intensity			15,293 Btu/bu	4.48 Kwh/lb
Fraction of energy used for starch processing and syrup concentra			24.5% (3)	
Fuel Intensity of Glucose Production			92,735 Btu/bu	1,656 Btu/lb
Electric Intensity of Glucose Production			11,547 Btu/bu	0.06 Kwh/lb

Notes: Significant processing of starch and glucose products (such as glucose concentration or starch modification) occurs in wet corn mills. To try and account for the most energy intensive aspects of this processing, the fraction of energy used for these processes from reference 7 has been deducted from the total wet mill energy intensity estimate. While this is a rather crude method, lacking additional data it will have to suffice.

Fuel Split					
Natural Gas			40,479 Btu/bu	40,479 Btu/bu	723 Btu/lb
Coal			52,255 Btu/bu	52,255 Btu/bu	933 Btu/lb
Electricity		Purchased	11,547 Btu/bu	3.38 Kwh/bu	6.04E-02 Kwh/lb
		Generated	1,597 Btu/bu	0.47 Kwh/bu	8.36E-03 Kwh/lb
Other Estimates Total			4,100 Btu/lb		
Less Syrup Concentration, starch drying, and dextr			3,096 Btu/lb	(3)	
kg steam	507,182,742	kg corn	579,078,355	lb steam/bu	49.05
NREL Estimate				Btu/bu	44,658
Assuming 80% efficiency boilers total fu			997		797
				229,600 Btu/bu	
				173,376 Btu/bu	

Electricity Use (kwh/yr)	Starch Use (kg/yr)	Corn Use to Produce Starch (kg/yr)	Energy Intensity (kwh/kg)	Energy Intensity (kwh/lb corn)
2,524,789	110,225,570	184,690,076	0.014	0.030

NREL Electricit

Because the NREL data has only recently been provided, and is still in the process of being updated, it was not possible to resolve the differences in estimates.

Notes: Based on this estimate the energy intensity of wet corn milling has dropped significantly since 1977. This seems fairly reasonable in such a long time frame. It can also be compared to the energy intensity estimate for ethanol 2,417 Btu/lb. This suggests that our estimate is at least in the ballpark for corn processing at wet mills.

Table 4 Electricity Balance in Wet Corn Milling Industry

Electricity Balance, Raw Input Data from MECS Tables 4, 16, 17. All data in million Kwh.

Estimated values (mine) are in bold type. Calculated values are in italics.

Transfers in are assumed to equal zero. Thus purchases equal the

sum of purchases and transfers in. Sales can be calculated for the Midwest and U.S.

regions as the difference between columns E and K. Next, conventional generation

can be calculated for the Midwest and U.S. regions from columns J - C + I. Finally

conventional generation in the West and South must be estimated. If the ratio of generation to purchases is assumed

to be the same in these two regions, successive guesses can be made until the

relationship is balanced. Using 15 million kwh conv. generation in the West, the remaining values can be calculated,

giving a reasonable balance to the table.

Region	Table 4 Purchases	Transfers In	Table 4 P&T in	Table 16 Gen. (conv.)	Table 17 Gen. (renew.)	E + F Total Onsite Gen.	Table 16 Sales and Transfers	Table 16 P&T in + Gen - Sale P&T in + Renew. - Sale Net Electricity
West	93		0	93	15	0	15	93
South	837		0	837	134	0	134	889
Midwest	3,199		0	3,199	1,617	0	1,617	4,809
Northeast	15		0	15	0	0	0	15
U.S.	4,143		0	4,143	1,766	0	1,766	5,820
U.S. (Quads)	14.14		0.00	14.14	6.03	0.00	6.03	19.86
							Balance Net Demand	
					ratio generation to purchases		0.161	1
					West		0.160	
					South			

Table 5 Emissions from Energy Consumption in Wet Corn Mills

- (1) U.S. EPA, AP-42, Sections 1.1 and 1.4
- (2) Personal Communication, Bob Bessette, Council of Industrial Boilers, 6-16-95.
- (3) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).
- (4) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

Emission Factor/Fuel	Pollutant	Category	Raw Input Quantity	Units	Source	Notes	Transformed Input Quantity
Gas	NOx	Uncontrolled		550 lb/million cubic feet	(1)		0.53346
		Low NOx		81 lb/million cubic feet	(1)		0.07856
		Flue Gas Recirc.		53 lb/million cubic feet	(1)		0.05141
		Average		308.5 lb/million cubic feet			0.29922
	SO2			0.6 lb/million cubic feet	(1)		0.00058
	PM-10			13.7 lb/million cubic feet	(1)		0.01329
	CO			40 lb/million cubic feet	(1)		0.03880
	CO2			14.47 million m tons carbon/Q4)			116.88885
	Non-Methane VOC's			1.411 lb/million cubic feet	(1)	Data are for small industrial boilers.	0.0137
	Methane			0.289 lb/million cubic feet	(1)	Uncontrolled emission factor. No data to	0.00028
Coal	NOx			22.276 Million btu/ton	(3)		
				15.2 lb/ton	(1)		0.68235
				22.1 lb/ton	(1)		0.99356
				13.2 lb/ton	(1)		0.59257
	PM-10			18 lb/ton	(1)		0.80804
	CO			25.58 million m tons carbon/Q4)			206.63558
	CO2			0.05 lb/ton	(1)		0.00224
	Non-Methane VOC's			0.06 lb/ton	(1)		0.00269
	Methane			5.7 lb/ton	(1)		0.25588
	N2O					Average of values for bubbling and circu	

SO2 emission factor estimate for fluidized bed coal boilers

SO2 emissions can be calculated as $SO_2 = 39.6 \cdot S \cdot (Ca/S)^{-1.9}$ where S is the sulfur percentage of the coal, and Ca/S is the calcium to sulfur ratio in the bed.

Ca/S	2.2 (ratio)	(2)
Sulfur percent	2.50 percent	(estimate)
SO2	22.1 lb/ton	(calculated)
	0.99 lb/mm btu	(calculated)

Fuel Related Emissions

	Units
NOx	0.04777 lb/bu
SO2	0.05194 lb/bu
PM-10	0.03150 lb/bu

CO	0.04380	lb/bu
CO2	15.52937	lb/bu
Non-Methane V	0.00017	lb/bu
Methane	0.00015	lb/bu
N2O	0.01337	lb/bu

Notes: According to Bob Bessett, fluidized bed boilers are the most common type used in this industry. Emissions from coal are thus estimated based on emission factors for this technology. Because fluidized bed boilers remove sulfur, it is possible to burn much higher sulfur content coal without surpassing limits on sulfur emissions. For utilities in Iowa, Illinois and Indiana, the average sulfur content of coal used was around 1.5% in 1993 (5). I assume a sulfur content of 2.50 percent to account for the use of cheap, high sulfur coal in FBC boilers.

Table 6 Toxic Releases from The Wet Corn Milling Industry

(1) U.S. EPA, Toxic Release Inventory, Data downloaded from Right To Know (RTK) Network online database.
(Raw data on sheet TOXICS)

(2) USDAVERS. 1993. Feed Situation and Outlook Report.

This Table includes data only on emissions of four toxics. For information on why other toxics categories were excluded, see the sheet TOXICS.

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

Year	Grind (million bu)	Ammonia Fug Air	Stack Air	Water	Land
1987	1104	416,721	1,000	50,250	50,459
1988	1160	68,669	3,686	161,420	250
1989	1221	81,151	5,052	710,368	1,450
1990	1221	19,706	8,332	776,472	6,865
1991	1318	18,264	5,384	427,024	13,576
1992	1375	16,252	4,437	266,877	0
1993	1413	71,687	1,725	56,649	0
Total		692,450	29,616	2,449,060	72,600

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

Year	Grind (million bu)	HCL Fug Air	Stack Air	Water	Land
1987	1104	16,578	20,996	0	4,750
1988	1160	11,331	7,870	0	750
1989	1221	16,055	32,073	11	1,011
1990	1221	14,241	34,203	5	1,000
1991	1318	12,987	1,261,725	600	27,000
1992	1375	7,214	955,691	250	200
1993	1413	12,010	977,391	0	15,910
Total		90,416	3,289,949	866	50,621

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

Year	Grind (million bu)	Chlorine Fug Air	Stack Air	Water	Land
1987	1104	1,500		0	0
1988	1160	3,670		10,252	0
1989	1221	7,172		12,000	0
1990	1221	2,755		10	0
1991	1318	2,501		159,896	0
1992	1375	1,267		155,055	0
1993	1413	2,487		4,887	1
Total		21,352		342,100	14,637

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

Year	Grind (million bu)	Sulfuric Acid Fug Air	Stack Air	Water	Land
1987	1104	1,002		538	13
1988	1160	1,751		1,013	0
1989	1221	1,504		791	0
1990	1221	1,032		59	755
1991	1318	268		61	0
1992	1375	272		104,443	0
1993	1413	532		120,459	5
Total		6,361		227,364	773

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

Year	Grind (million bu)	Ammonia Fug Air	Stack Air	Water	Land
1987	1104	3.77E-04		9.08E-07	4.57E-05
1988	1160	5.92E-05		3.18E-06	2.16E-07
1989	1221	6.65E-05		4.14E-06	1.19E-06
1990	1221	1.61E-05		6.82E-06	5.62E-06
1991	1318	1.39E-05		4.08E-06	1.03E-05
1992	1375	1.18E-05		3.23E-06	0
1993	1413	5.07E-05		1.22E-06	0
Average		8.51E-05		3.37E-06	9.00E-06

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

Year	Grind (million bu)	HCL Fug Air	Stack Air	Water	Land

Year	Grind (million bu)	Chlorine Fug Air	Stack Air	Water	Land
1987	1104	1.50E-05	1.90E-05	0	4.30E-06
1988	1160	9.77E-06	6.78E-06	0	6.47E-07
1989	1221	1.31E-05	2.63E-05	9.01E-09	8.28E-07
1990	1221	1.17E-05	2.80E-05	4.10E-09	8.19E-07
1991	1318	9.85E-06	9.57E-04	4.53E-07	2.03E-05
1992	1375	5.25E-06	6.95E-04	1.82E-07	1.45E-07
1993	1413	8.50E-06	6.92E-04	0	1.13E-05
Average		1.05E-05	3.46E-04	9.29E-08	5.50E-06

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

Year	Grind (million bu)	Chlorine Fug Air	Stack Air	Water	Land
1987	1104	1.36E-06	0.00E+00	2.26E-07	0
1988	1160	3.16E-06	8.84E-06	2.16E-07	0
1989	1221	5.87E-06	9.83E-06	2.05E-07	0
1990	1221	2.26E-06	8.19E-09	1.05E-06	0
1991	1318	1.90E-06	1.21E-04	8.48E-06	0
1992	1375	9.21E-07	1.13E-04	1.04E-06	0
1993	1413	1.76E-06	3.46E-06	7.08E-10	7.08E-10
Average		2.46E-06	3.66E-05	1.60E-06	1.01E-10

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

Year	Grind (million bu)	Sulfuric Acid Fug Air	Stack Air	Water	Land
1987	1104	9.08E-07	4.87E-07	1.18E-08	0
1988	1160	1.51E-06	8.73E-07	0	0
1989	1221	1.23E-06	6.48E-07	0	0
1990	1221	8.45E-07	4.83E-08	6.18E-07	0
1991	1318	2.03E-07	4.63E-08	0	0
1992	1375	1.98E-07	7.60E-05	0	0
1993	1413	3.77E-07	8.53E-05	3.54E-09	8.37E-07
Average		7.53E-07	2.33E-05	9.05E-08	1.20E-07

Notes: for some emission pathways and pollutants the quantities are very small, and may be the result of a single emission from a single plant in a particular year. The resulting emission intensity thus becomes rather low. I have reset these values to zero since they represent outliers, and since the impact at such low levels of emission would be negligible. These include land emissions of chlorine, sulfuric acid, and HCL, and water emissions of HCL and sulfuric acid. Some of the remaining emissions may still be of negligible quantity.

Table 7 Particulate Emissions from Corn Milling Operations

(from test and pControlled Controlled	0.3 lb/ton 0.7 lb/ton	(3) (3)	There is clearly something this data. Not only are lower than controlled factors, but the average recommended than the range of test a values.	0.00204 lb/bushel corn 0.00476 lb/bushel corn	Converted based on the fraction of feed pro Converted based on the fraction of feed pro
Uncontrolled Uncontrolled	0.2 lb/ton 1 lb/ton	(3) (3)		0.00136 lb/bushel corn 0.00680 lb/bushel corn	Converted based on the fraction of feed pro Converted based on the fraction of feed pro
Uncontrolled	10 lb/ton	(3)		0.06801 lb/bushel corn	Converted based on the fraction of feed pro
Total Particulate Emissions	1.3 lb/ton 17.9 lb/ton	(4) (4)	Range of values	0.03640 lb/bushel corn 0.50120 lb/bushel corn	Converted based on the lb of corn per bush Converted based on the lb of corn per bush
Emission Values Used					
Receiving	0.5165 lb/ton	Average of controlled and uncontrolled values.		0.01446 lb/bushel corn	Converted based on the lb of corn per bush
Handling	0.33 lb/ton	Average of controlled values averaged with unco		0.00924 lb/bushel corn	Converted based on the lb of corn per bush
Cleaning	0.885 lb/ton	Average of controlled and uncontrolled values.		0.02478 lb/bushel corn	Converted based on the lb of corn per bush
Drying	0.845 lb/ton	Average of controlled values. This may understate emissions significantly.		0.00575 lb/bushel corn 0.05423 lb/bushel corn	Converted based on the fraction of feed pro Converted based on the fraction of feed pro
Total					

Notes: for most emission categories the difference between controlled and uncontrolled is not too dramatic. Thus the lack of data on the prevalence of controls is not a serious problem. For drying, however, the range of values is quite large, or about two orders of magnitude. Clearly the assumption about how to estimate the prevalence of controls on feed dryers is important. I used the average of 6 controlled values, assuming controls are common.

Table 8 Water Emissions from the Wet Corn Milling Industry

- (1) Grogan, P.J., and D. J. Santini. 1981. Overview of Environmental Problems in the Food Industry. in Proceedings of the 36th Industrial Waste Conference, May 12-14, 1981, Lafayette, IN.
- (2) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.
- (3) Code of Federal Regulations, 40 CFR 406.15, 1994 edition.

Water	Quantity BOD5 TSS	Raw Input Quantity			Average	Units	Source	Notes	Transformed Quantity
		Low	High						
			0.75	10		4.4 gallons/ton	(1)	Based on early 1970's data	0.1232
			4.2	25		14.8 lb/ton	(1)	Based on early 1970's data	0.4144
			1	19.6		7.5 lb/ton	(1)	Based on early 1970's data	0.21
Water	Quantity BOD5 TSS	25 1000		35 3000		30 gallons/bu 2000 ppm 500 ppm	(2) (2) (2)	before treatment	30 0.5007 0.028
EPA Limits (30 day average) TSS	BOD5					20 lb/k bu 25 lb/k bu	(3) (3)	Standards of performance for new sources, after treatment	0.02 0.025

pH 6.0 9.0 (3)

Table 9 Water Consumption in Wet Corn Mills

(1) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

(2) NREL Model

Water Use	Raw Input Quantity	Units	Source:	Transformed Quantity Units	Notes:
	30-40	Gallons/bu	(1)	35 Gallons/bu	Average of estimated range
Process	1.43	kg water/kg corn	(2)	10 Gallons/bu	
Cooling Tower	16.58	kg water/kg corn	(2)	111 Gallons/bu	

Table 10 Material Balance in Wet Corn Mills

(1) Corn Refiners Association, Inc. 1994?. 1994 Corn Annual, Corn Refiners Association, Washington, D.C.

(2) Murray, B.C., D.H. Gross, and T.J. Fox. 1994. Starch Manufacturing: A Profile, Final report to the U.S. EPA by the Center for Economics and Research, Research Triangle Park, NC.

(3) USDA/ERS. 1994. Sugar and Sweetener: Situation and Outlook Report, SSSV 19N2, June 1994.

(4) U.S. Department of Commerce, Bureau of the Census. 1994. 1992 Census of Manufactures: Grain Mill Products, MC92-I-20D(P).

(5) Whistler, R. L., J.N. BeMiller, and E.F. Paschall (ed.). 1984. Starch: Chemistry and Technology, Academic Press, NY.

(6) National Corn Growers Association, and National Corn Development Foundation. 1995. The World of Corn: 1995.

(7) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

(8) Austin, George T. 1984. Shreve's Chemical Process Industries, fifth edition, McGraw Hill, New York.

Shipments of Corn Refining Products (MRaw Input Quantity

Source	(1)	(2)	(3)	(3)	(3)	(2)	(2)	ERS 1992 (3)	ERS 1993 (3)
Units	Million lbs	Million lbs	Thousand sh tons dry	Thousand sh tons dry	Thousand sh tons dry wt.	Million lbs	Million lbs	Million lbs	Million lbs
Year	1993	1993	1992	1992	1993	1993	1992	1992	1993
CORN STARCH		5,556		6,340			6,340		
SYRUPS		26,955							
HFCS 42		8,140	2,812		2,951			7,921	8,313
HFCS 55		10,441	3,871		4,198			10,055	10,904
HFCS TOTAL		18,580	6,683		7,149			17,976	19,217
TOTAL DOMES		32,511							

TOTAL EXPOR	739	739	Average
CORN OIL	799	799	
G. FEED, C. OI	11,388	11,388	Notes: The Corn Refiners only their members. ERS es this percentage is the e
GLUTEN MEAL	2,031	2,031	
STEEPWATER	458	458	
TOTAL SHIPME	47,926	47,926	
CORN STARCH	6340	6340	
WHEAT STARCH	276	276	
POTATO STARCH	207	207	
TAPIOCA STARCH	69	69	
TOTAL STARCH	6,892	6,892	

Notes: Information is presented here from three sources for comparison. Based on the ERS and Corn Refiners data it appears that Corn Refiners members produce nearly all of the starch and corn syrup products. On this basis the corn refiners commercial shipments numbers are converted to dry weight to complete a mass balance.

Shipments of Corn Refining Products (Million lbs)

	Raw Input Quantity	Units	Source	Notes	Transformed Input Quantity	Units	Notes
CORN STARCH	5,556	Million lbs	(1)	I added the category "other glucose" to account for the difference between refinery products, which includes all of the syrups, and the totals for HFCS.	5,556	Million lbs dry wt.	Commercial wt. equals dry wt.
REFINERY PR	26,955	Million lbs	(1)				
OTHER GLUCO	8,375	Million lbs	(1)		7,286	Million lbs dry wt.	Estimate at 85% solids.
HFCS 42	8,140	Million lbs	(1)		5,779	Million lbs dry wt.	71% solids (3).
HFCS 55	10,441	Million lbs	(1)		8,039	Million lbs dry wt.	77% solids (3).
HFCS TOTAL	18,580	Million lbs	(1)				
TOTAL DOMES	32,511	Million lbs	(1)				
TOTAL EXPOR	739	Million lbs	(1)		799	Million lbs dry wt.	Estimated as commercial
CORN OIL	799	Million lbs	(1)		11,388	Million lbs dry wt.	weight equals dry weight
G. FEED, C. OI	11,388	Million lbs	(1)		2,031	Million lbs dry wt.	for these products.
GLUTEN MEAL	2,031	Million lbs	(1)		229	Million lbs dry wt.	50% solids (7).
STEEPWATER	458	Million lbs	(1)		41,107	Million lbs dry wt.	
TOTAL SHIPME	47,926	Million lbs	(1)				
WATER	-	Million lbs	(1)				

Notes: The wt. fraction of corn ending up in each product type is calculated based on the total consumption of corn by the wet corn milling industry, excluding corn grind for ethanol. Since this is based on dry weight, the difference between the total dry wt. and the wt. of corn used, gives the fraction of water in the corn, as received. Th 12.32% is reasonable, so it is assumed that our calculations are relatively representative of the industry.

Total Wet Corn Mill Consumption of Corn

Year	Raw Input Quantity	Units	Source	Transformed Quantity	Units
1987	723	Million Bushels	(3)	40,488	Million lbs
1988	757	Million Bushels	(3)	42,392	Million lbs
1989	766	Million Bushels	(3)	42,896	Million lbs

1990	791 Million Bushels	(3)	44,296 Million lbs
1991	811 Million Bushels	(3)	45,416 Million lbs
1992	839 Million Bushels	(3)	46,984 Million lbs
1993	865 Million Bushels	(3)	48,440 Million lbs
1994	905 Million Bushels	(3)	50,680 Million lbs

Conversion of Glucose Quantity into Relative Starch Quantity (to account for gain in mass from conversion process).

Chemical Gain	Raw Input Quantity	Source	Notes	Average
	4.10% (8)		p. 572	
	5.80% (3)		p. 70	
	11.11% (7)		p. 219, Based on Stoichiometry	
We Use	4.95%		Average of two estimated values	

Total Sugars Starch Equivalent Units
21,105 20,109 Million lbs dry wt.

Comparison of Estimates of Theoretical Yield with Calculated Value from ERS and CRA Data.

Based on CRA					
Theoretical Yield/Annual Prod.	(lb)	ERS (3) (lb/bu)	%	CGA (6) (lb/bu)	%
Corn In	46,883		56		56.00
Starch	25,665	54.74%	31.5	56.25%	57.14%
Oil (crude)	799	1.70%	1.55	2.77%	2.86%
Gluten Feed	11,388	24.29%	13.5	24.11%	20.36%
Gluten Meal	2,031	4.33%	2.65	4.73%	5.36%
Steepwater	229	0.49%	-		
Water	6,771	14.44%	6.8	12.14%	14.29%
Total	40,112	85.56%	49.2	87.86%	85.71%
					59.68%
					4.03%
					12.70%
					4.33%
					80.75%

Notes: The calculated yields are thus reasonable. Oil yield is lower than both the ERS and CGA theoretical values. This may be because some corn germ is sold to non-CRA refiners.

Material Balance Based on ERS and CRA Data

Annual Prod Referenced to 1 Bushel	Quantity	Units
Corn In	56 lb	
Starch	30.66 lb	
Oil	0.95 lb	
Gluten Feed	13.60 lb	
Gluten Meal	2.43 lb	

If all starch were converted to Glucose, the yield would be:

Quantity	Units
Corn in	56 lb
Glucose	32.17 lb
Oil	0.95 lb
Gluten Feed	13.60 lb
Gluten Meal	2.43 lb

Table 11 Sulfur Dioxide Use in Wet Corn Milling Industry

(1) U.S. EPA, AP-42, Section 9.9.7

(2) NREL Wet Corn Milling Model

Input	Quantity	Units	Source	Transformed Quantity
Sulfur Dioxide	low	0.06 lb/bu	(1)	0.06
	high	0.11	(1)	0.11
	average	0.00206 kg/kg corn	(2)	0.12
Sulfur Use				0.058

Notes: Sulfur dioxide use is converted to sulfur use using the ratio of weights of sulfur and sulfur dioxide.

Table 12 Ash Production from Coal Consumption

(1) Utility Data Institute. 1995. EEI Power Statistics Database.

(2) Babcock and Wilcox. 1992. Steam: Its Generation and Use, 40th Edition, S.C. Stulz and J.B. Kitto (eds.).

(3) Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

(4) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

There are two sources of ash in FBC systems, the naturally occurring ash in the coal, and ash formed from sulfur combining with the calcium in the bed. This reaction involves the conversion of calcium carbonate into calcium oxide ($\text{CaCO}_3 \rightarrow \text{CaO}$) and the subsequent formation of CaSO_4 from SO_2 . Thus two moles of SO_2 are removed for every mole of Ca. In addition, CO_2 is emitted in the process.

Reactions	Source
$\text{CaCO}_3 \rightarrow \text{CaO(s)} + \text{CO}_2 \text{ (g)}$	(2)
$\text{SO}_2 \text{ (g)} + 1/2 \text{ O}_2 \text{ (g)} + \text{CaO (s)} \rightarrow \text{CaSO}_4 \text{ (s)}$	(2)

Ash Production from Coal Ash and Sulfur Removal

Value	Units	Source	Notes
Coal Sulfur Con	2.50 Percent	Estimate	
Coal Ash Conte	7.70 Percent	(1)	
Coal Energy Co	22.276 Million Btu/ton	(3)	
Energy Consum	52,255 Btu/bu	Table 3	
Energy Consum	0.0023 tons coal/bu	Calculated	
Energy Consum	4.69 lb coal/bu	Calculated	
Ash From Coal	0.36 lb/bu	Calculated	
Ash From Sulfu	118.33 lb/ton coal	Calculated	
Ash From Sulfu	0.28 lb/bu	Calculated	
Total Ash	0.64 lb/bu	Calculated	

Reference (1) data indicates that the utility average sulfur content in Iowa, Indiana and Illinois in 1953 was about 1.5%.

Carbon Dioxide Production from Limestone Consumption

Quantity	Units	Notes:
Sulfur Removal	27.87 lb sulfur removed per ton c	Calculated as the total sulfur in Coal minus that emitted from emissions table above.
Carbon Dioxide	38.25 lb CO2 emitted per ton coal	Based on Stoichiometry
Carbon Dioxide	0.09 lb/bu	

ality poor.
ality poor.
ality poor.

	Table 5	Table 12	Table 7	Table 6	Table 5	Table 12	Table 7	Table 6
	Energy Cons.	From CaCO3	WM Particula	Toxic Release	Energy Con	From CaCO3	Particu	Toxic Relea
NOx	4.78E-02	-	-	-	100.00%	-	-	100.00%
SOx	5.19E-02	-	-	-	100.00%	-	-	100.00%
PM-10	3.15E-02	-	-	-	100.00%	-	-	100.00%
Total Particula	-	-	5.42E-02	-	-	-	100.00%	-
CO	4.38E-02	-	-	-	100.00%	-	-	100.00%
CO2	1.55E+01	8.97E-02	-	-	99.43%	0.57%	-	100.00%
Non-Methane	1.73E-04	-	-	-	100.00%	-	-	100.00%
Methane	1.52E-04	-	-	-	100.00%	-	-	100.00%
N2O	1.34E-02	-	-	-	100.00%	-	-	100.00%
HCL	-	-	-	-	-	-	-	-
Ammonia	-	-	-	3.57E-04	-	-	-	100.00%
Chlorine	-	-	-	8.85E-05	-	-	-	100.00%
Sulfuric Acid	-	-	-	3.91E-05	-	-	-	100.00%
	-	-	-	2.41E-05	-	-	-	100.00%

ry aggregate data.
ry aggregate data.
ry aggregate data.

conforms to other published estimates.
conforms to other published estimates.
conforms to other published estimates.
conforms to other published estimates.
conforms to other published estimates.

This table contains raw data on the release of toxic materials by the wet com milling industry. The data was downloaded from the TRI database, as accessed through the RTK (Right To Know) network in June of 1995. Because of difficulty in downloading a suitably formatted electronic data set, the information was instead compiled from a hard copy report. The data were input to this spreadsheet and extensively checked, however there is always the possibility of error.

The raw data include information on a fairly large number of pollutants. Seven of the facilities listed here provided information on the route from which each toxic release was generated. Responses by each facility were consistent, and indicate that most of the toxic material released is associated with processes such as corn starch modification, ion exchange resin regeneration, and ethanol production. Since these processes are not necessary to the production of glucose, these emissions are not assigned to glucose manufacture. The toxics that are associated with glucose manufacture are ammonia, HCl, chlorine, and sulfuric acid. The list below gives a brief description of how each of the toxic chemicals associated with wet corn milling are used.

Hydrochloric Acid	Used for ion exchange regeneration, pH adjustment, and in some cases for conversion of starch to glucose.
Ammonia	Used as a nutrient (nitrogen source) in either wastewater treatment or for fermentation.
Sulfuric Acid	Used as a pH adjuster and for ion exchange regeneration.
Chlorine	Used to treat well water or cooling water. Some chlorine emissions may be associated with coal combustion emissions to the stack.
Ammonium Sulfate	Probably also associated with use of ammonia as nutrient.

Ethylene Oxide	Used to modify starches
Propylene Glycol	From the reaction of ethylene oxide with water.
Propylene Oxide	Used to modify starches
Propylene Glycol	From the reaction of propylene oxide with water.
Phosphoric Acid	Used for ion exchange regeneration and as nutrient in wastewater.
Methanol	Byproduct of ethanol production?

Acetaldehyde	?	
Sodium Sulfate	?	
Sodium Hydroxide		Used for pH control.
Freon 113		Refrigerant.

Peracetic Acid
Cyclohexane

Lead Compounds
Nickel Compounds
Selenium
Vanadium
Barium
Manganese

Styrene ?
Butadiene ?
Ammonium Nitrate Probably also associated with use of ammonia as nutrient.

Methanol	Byproduct of ethanol production?	This set of pollutants is associated with the large
Epichlorohydrin	Used to modify starches.	ADM facilities which produce ethanol. I am
1-bromodichloroethane	Refrigerant.	assuming that they are thus associated with
Bromotrifluoroethane	Refrigerant.	processes other than the basic glucose
Trichlorofluoroethane	Refrigerant.	manufacture.

Refrigerant	?	?	?	?	?	?	?
Dichlorodifluoromethane							
Hydrogen Fluoride							
Toluene							
Benzene							
4-Butyl Alcohol							
Ethyl Acetate							
Ethylene							

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

Year	Grind (million bu)	Ammonia			HCL			Chlorine			Sulfuric Acid						
		Fug Air	Stack Air	Water	Land	Fug Air	Stack Air	Water	Land	Fug Air	Stack Air	Water	Land				
1987	1104	416721	1000	50250	50459	16578	20996	0	4750	1500	0	250	0	1002	538	13	0

1988	1160	68669	3886	161420	250	11331	7870	0	750	3,670	10,262	250	0	1,751	1,013	0	0
1989	1221	81151	5052	170368	1450	16055	32073	11	1011	17,172	12,000	250	0	1,504	791	0	0
1990	1221	19706	8332	776472	6865	14241	34203	5	1000	2,755	10	1,277	0	1,032	59	755	0
1991	1318	18264	5384	427024	13576	12987	1261725	600	27000	2,501	159,896	11,176	0	268	61	0	0
1992	1375	16252	4437	266877	0	7214	955691	250	200	1,267	155,055	1,433	0	272	104,443	0	0
1993	1413	71687	1725	56649	0	12010	977391	0	15910	2,487	4,887	1	1	532	120,459	5	1,182
		692450	29616	2449060	72600	90416	3289949	866	50621	21,352	342,100	14,637	0	3,361	227,364	773	1,182
		692450	29616	2449060	72600	90416	3289949	866	50621	21,352	342,100	14,637	1	6,361	227,364	773	1,182

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)
Based on total corn grind for starch products, byproducts, and ethanol production.

Year	1987	1988	1989	1990	1991	1992	1993	1987	1988	1989	1990	1991	1992	1993	1987	1988	1989	1990	1991	1992	1993	1987	1988	1989	1990	1991	1992	1993	1987	1988	1989	1990	1991	1992	1993
	1104	1160	1221	1221	1318	1375	1413	1104	1160	1221	1221	1318	1375	1413	1104	1160	1221	1221	1318	1375	1413	1104	1160	1221	1221	1318	1375	1413	1104	1160	1221	1221	1318	1375	1413
	0.000377465	5.91974E-05	6.64627E-05	1.61392E-05	1.38574E-05	1.18196E-05	5.07339E-05	0.000377465	5.91974E-05	6.64627E-05	1.61392E-05	1.38574E-05	1.18196E-05	5.07339E-05	0.000377465	5.91974E-05	6.64627E-05	1.61392E-05	1.38574E-05	1.18196E-05	5.07339E-05	0.000377465	5.91974E-05	6.64627E-05	1.61392E-05	1.38574E-05	1.18196E-05	5.07339E-05	0.000377465	5.91974E-05	6.64627E-05	1.61392E-05	1.38574E-05	1.18196E-05	5.07339E-05
	4.6E-05	2.2E-07	1.2E-06	5.6E-06	1E-05	0.00032	4E-05	4.6E-05	2.2E-07	1.2E-06	5.6E-06	1E-05	0.00032	4E-05	4.6E-05	2.2E-07	1.2E-06	5.6E-06	1E-05	0.00032	4E-05	4.6E-05	2.2E-07	1.2E-06	5.6E-06	1E-05	0.00032	4E-05	4.6E-05	2.2E-07	1.2E-06	5.6E-06	1E-05	0.00032	4E-05
	9.1E-07	3.2E-06	4.1E-06	6.8E-06	4.1E-06	3.2E-06	1.2E-06	9.1E-07	3.2E-06	4.1E-06	6.8E-06	4.1E-06	3.2E-06	1.2E-06	9.1E-07	3.2E-06	4.1E-06	6.8E-06	4.1E-06	3.2E-06	1.2E-06	9.1E-07	3.2E-06	4.1E-06	6.8E-06	4.1E-06	3.2E-06	1.2E-06	9.1E-07	3.2E-06	4.1E-06	6.8E-06	4.1E-06	3.2E-06	1.2E-06
	0.000377465	5.91974E-05	6.64627E-05	1.61392E-05	1.38574E-05	1.18196E-05	5.07339E-05	0.000377465	5.91974E-05	6.64627E-05	1.61392E-05	1.38574E-05	1.18196E-05	5.07339E-05	0.000377465	5.91974E-05	6.64627E-05	1.61392E-05	1.38574E-05	1.18196E-05	5.07339E-05	0.000377465	5.91974E-05	6.64627E-05	1.61392E-05	1.38574E-05	1.18196E-05	5.07339E-05	0.000377465	5.91974E-05	6.64627E-05	1.61392E-05	1.38574E-05	1.18196E-05	5.07339E-05

Average

Plant Level Data
Toxic Releases in SIC 2046 - Wet Corn Milling
Emissions in lbs

Fugitive Air

Plant	City	Year	Hydrochloric Acid	Ammonium Chloride	Sulfuric Acid	Ethylene Glycol	Propylene Glycol	Phosphoric Acid	Methanol	Acetaldehyde	Epichlorohydrin	Sodium Hydroxide	Bromotrifluoride
American Maize Products	Decatur	1987	250	0	0	0	0	0	0	0	0	0	0
		1988	250	0	0	0	0	0	0	0	0	0	0

A. E. Staley Mfg. Co.

Van Buren

77000

0

CPC International Inc.

Stockton

250

0

A. E. Staley Mfg. Co.

Monte Vista

1000

0

[illegible]

Plant	City	Year	Toxic Releases in SIC 2046 - Wet Corn Milling Emissions in lbs										
			Hydrochloric Acid	Ammonium Chloride	Sulfuric Acid	Ethylene Glycol	Propylene Glycol	Phosphoric Acid	Methanol	Sodium Sulfide	Sodium Hydroxide	Acetaldehyde	Dibromonit
American Maize Products	Dimmitt	1988	0	250	0	250	250	250	250	250	250	250	250
		1989	0	250	0	250	250	250	250	250	250	250	250
		1990	5	250	5	250	250	250	250	250	250	250	250
		1991	5	5	5	5	5	5	5	5	5	5	5
		1992	5	250	5	250	250	250	250	250	250	250	250
		1993	1700	250	5	250	250	250	250	250	250	250	250
		1987	250	250	250	250	250	250	250	250	250	250	250
		1988	250	250	250	250	250	250	250	250	250	250	250
		1989	250	250	250	250	250	250	250	250	250	250	250
		1990	250	250	250	250	250	250	250	250	250	250	250
CPC	Winston-Salem	1988	250	250	250	250	250	250	250	250	250	250	250
		1989	250	250	250	250	250	250	250	250	250	250	250
		1990	250	250	250	250	250	250	250	250	250	250	250
		1991	250	250	250	250	250	250	250	250	250	250	250
		1992	250	250	250	250	250	250	250	250	250	250	250
		1993	250	250	250	250	250	250	250	250	250	250	250
		1987	800	250	250	250	250	250	250	250	250	250	250
		1988	750	250	250	250	250	250	250	250	250	250	250
		1989	750	250	250	250	250	250	250	250	250	250	250
		1990	750	250	250	250	250	250	250	250	250	250	250
Total		1988	16,578	4,167.21	0	1,500	1,002	1,500	0	8,531	0	77,000	0
		1989	11,331	68,669	0	3,670	1,751	17,376	0	276,916	0	276,916	0
		1990	16,055	81,151	250	7,172	1,504	1,539	0	120,912	250	120,912	0
		1991	14,241	19,706	250	2,755	1,032	1,750	0	110,000	250	110,000	0
		1992	12,987	18,264	0	2,501	268	780	0	42,000	5	42,000	0
		1993	7,214	16,252	0	1,267	272	320	0	25,000	5	25,000	0
		1987	71,687	98,921	0	2,487	532	428	0	22,900	5	22,900	0
		1988	12,917	98,921	71	3,050	909	3,385	0	96,390	74	96,390	0
		1989	12,917	98,921	71	3,050	909	3,385	0	96,390	74	96,390	0
		1990	12,917	98,921	71	3,050	909	3,385	0	96,390	74	96,390	0
Average		1988	16,578	4,167.21	0	1,500	1,002	1,500	0	8,531	0	77,000	0
		1989	11,331	68,669	0	3,670	1,751	17,376	0	276,916	0	276,916	0
		1990	16,055	81,151	250	7,172	1,504	1,539	0	120,912	250	120,912	0
		1991	14,241	19,706	250	2,755	1,032	1,750	0	110,000	250	110,000	0
		1992	12,987	18,264	0	2,501	268	780	0	42,000	5	42,000	0
		1993	7,214	16,252	0	1,267	272	320	0	25,000	5	25,000	0
		1987	71,687	98,921	0	2,487	532	428	0	22,900	5	22,900	0
		1988	12,917	98,921	71	3,050	909	3,385	0	96,390	74	96,390	0
		1989	12,917	98,921	71	3,050	909	3,385	0	96,390	74	96,390	0
		1990	12,917	98,921	71	3,050	909	3,385	0	96,390	74	96,390	0

Toxic Releases in SIC 2046 - Wet Corn Milling Emissions in lbs

Plant	City	Year	Toxic Releases in SIC 2046 - Wet Corn Milling Emissions in lbs										
			Hydrochloric Acid	Ammonium Chloride	Sulfuric Acid	Ethylene Glycol	Propylene Glycol	Phosphoric Acid	Methanol	Sodium Sulfide	Sodium Hydroxide	Acetaldehyde	Dibromonit
American Maize Products	Decatur	1987	750	250	0	250	250	250	250	250	250	250	250
		1988	750	250	0	250	250	250	250	250	250	250	250
		1989	750	250	0	250	250	250	250	250	250	250	250
		1990	750	250	0	250	250	250	250	250	250	250	250
		1991	750	250	0	250	250	250	250	250	250	250	250
		1992	750	250	0	250	250	250	250	250	250	250	250
		1993	750	250	0	250	250	250	250	250	250	250	250
		1987	750	250	0	250	250	250	250	250	250	250	250
		1988	750	250	0	250	250	250	250	250	250	250	250
		1989	750	250	0	250	250	250	250	250	250	250	250
A. E. Staley Mfg. Co.	Van Buren	1987	750	250	0	250	250	250	250	250	250	250	250
		1988	750	250	0	250	250	250	250	250	250	250	250
		1989	750	250	0	250	250	250	250	250	250	250	250
		1990	750	250	0	250	250	250	250	250	250	250	250
		1991	750	250	0	250	250	250	250	250	250	250	250
		1992	750	250	0	250	250	250	250	250	250	250	250
		1993	750	250	0	250	250	250	250	250	250	250	250
		1987	750	250	0	250	250	250	250	250	250	250	250
		1988	750	250	0	250	250	250	250	250	250	250	250
		1989	750	250	0	250	250	250	250	250	250	250	250
CPC International Inc.	Stockton	1987	750	250	0	250	250	250	250	250	250	250	250
		1988	750	250	0	250	250	250	250	250	250	250	250
		1989	750	250	0	250	250	250	250	250	250	250	250
		1990	750	250	0	250	250	250	250	250	250	250	250
		1991	750	250	0	250	250	250	250	250	250	250	250
		1992	750	250	0	250	250	250	250	250	250	250	250
		1993	750	250	0	250	250	250	250	250	250	250	250
		1987	750	250	0	250	250	250	250	250	250	250	250
		1988	750	250	0	250	250	250	250	250	250	250	250
		1989	750	250	0	250	250	250	250	250	250	250	250
A. E. Staley Mfg. Co.	Monte Vista	1987	750	250	0	250	250	250	250	250	250	250	250
		1988	750	250	0	250	250	250	250	250	250	250	250
		1989	750	250	0	250	250	250	250	250	250	250	250
		1990	750	250	0	250	250	250	250	250	250	250	250
		1991	750	250	0	250	250	250	250	250	250	250	250
		1992	750	250	0	250	250	250	250	250	250	250	250
		1993	750	250	0	250	250	250	250	250	250	250	250
		1987	750	250	0	250	250	250	250	250	250	250	250
		1988	750	250	0	250	250	250	250	250	250	250	250
		1989	750	250	0	250	250	250	250	250	250	250	250

[illegible]

A. E. Slatley Mfg. Co. (Sagamo Lafayette)

1987	0	0	0	71576	0	129	0
1988	11	0	0	51259	0		0
1989	11	250	0		0		0
1990	250	0	0	33961	0		0
1991	250	0	0	31819	0		0
1992	250			24985			
1993	250			29250			

Minnesota Corn Processors Marshall

1987	0	0	0				
1988	0	0	0				
1989	0	0	0				
1990	0	0	0				
1991	0	0	0				
1992	250	0	0				
1993	250	0	0				

National Starch & Chemical Co Kansas City

1987	404	0	13	5594	0	0	9
1988	200	1936	13	14574	1	7	
1989	442	2312	15	5376	3		
1990	596	5797	14	7219	3		
1991	868	3219	14	8037	3		0
1992	1027	2927	15	9254	3		
1993	2	0	0	0	3		

Minnesota Corn Processors Columbus

1987							
1988							
1989							
1990							
1991							
1992							
1993							

ADM Corn Processing Montezuma

1987	250		0		5		
1988	0	0	0		5		
1989	0	0	0		0		
1990			0		0		
1991			0		0		
1992			0		0		

Cargill Inc. Dayton

1987	232	0	0			0	0
1988	330	0	0			0	0
1989	200	0	0				
1990	70	0	0				
1991	7000	0	0				
1992	76580	0	0				
1993	89350	0	83000				

A. E. Slatley Mfg. Co. Loudon

1987	750	0	0			0	0
1988	750	0	0			0	0
1989							
1990	250	5	5				
1991	51	5	5				0
1992	40	5	5				

Cargill Inc. Memphis

1987	456	0	0			0	0
1988	1000	0	0			0	0
1989	1300	740	0				
1990	1247	0	0				
1991	5848	0	0				
1992	69200	0	10200				
1993	75600	0	11200				

ADM Corn Processing Decatur

1987	250	250	0			250	250
1988	250	250	0			250	250
1989	250	250	0			250	250
1990	250	250	0			250	250

Plant	City	Year	Toxic Releases in SIC 2046 - Wet Corn Milling Emissions in lbs													
			Hydrochloric Acid	Ammonia	Ammonium Chloride	Sulfuric Acid	Ethylene Glycol	Propylene Glycol	Phosphoric Acid	Methanol	Sodium Sulfate	Sodium Hydroxide	Hydrogen Chloride	Acetaldehyde	Epichlorohydrin	Dibromomethane
American Maize Products	Hammond	1991	250	250	0	0	5			250						0
		1992	250	250	0	0	5									0
		1993	250	250												
		1987	250	250	0	0		44852		250	0					
		1988	250	250	0	0		5867								
		1989	250	250	0	0		750								
		1990	250	250	0	0		65600								
		1991	5	250	5	5		65991								
		1992	3942	250	250	250		5857								
		1993	3991	250	5	5		34886								
		1987	1500	250				42000								
		1988	250	250						250						
CPC	Winston-Salem	1987	4000	250			250									
		1988	750	250			250									
		1989	25000	250			250									
		1990	27000	250			5									
		1991	29000	250												
		1992	32000	250			5									
		1993	30000	250			5									
		1987	20,996	1,000	0	0	538	48,011	0	205,172	0	215,000	379	1,097	0	35,000
		1988	7,870	3,686	0	10,252	1,013	4,227	250	93,549	0	1	200,000	0	1,053	0
		1989	32,073	5,052	250	12,000	791	70,110	250	125,174	0	3	179,849	0	0	250
		1990	34,203	6,332	500	10	59	68,254	5	81,885	0	3	200,428	0	0	250
		1991	#####	5,384	0	159,896	61	8,777	5	64,725	0	3	78,250	0	0	6,300
		1992	955,691	4,437	0	155,055	104,443	717	5	84,622	0	8	30,005	0	72,000	750
		1993	977,391	1,725	0	4,887	120,459	752	5	181,080	0	3	4,500	0	62,000	750
		Average	469,993	4,231	107	48,871	32,481	28,693	74	119,458	0	3	129,719	54	307	18,143

Toxic Releases in SIC 2046 - Wet Corn Milling Emissions in lbs

Water

Plant	City	Year	Hydrochloric Acid	Ammonia	Ammonium Chloride	Sulfuric Acid	Ethylene Glycol	Propylene Glycol	Phosphoric Acid	Methanol	Sodium Sulfate	Sodium Hydroxide	Hydrogen Chloride	Acetaldehyde	Epichlorohydrin	Dibromomethane
American Maize Products	Decatur	1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A. E. Staley Mfg. Co.	Van Buren	1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CPC International Inc.	Stockton	1987	0	82	0	0	5	5	5	5	5	5	5	5	5	5
		1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	1983	1987	1988	1989	1990	1991	1992	1993	1987	1988	1989	1990	1991	1992	1993	1987	1988	1989	1990	1991	1992	1993	1987	1988	1989	1990	1991	1992	1993	1987	1988	1989	1990	1991	1992	1993	1987	1988	1989	1990	1991	1992	1993	1987	1988	1989	1990	1991	1992	1993
A. E. Staley	0																																																	
Monte Vista																																																		
ADM Corn Processing																																																		
Clinton																																																		
Hubinger Co.																																																		
Keokuk																																																		
ADM Corn Processing																																																		
Cedar Rapids																																																		
Cargill Inc.																																																		
Cedar Rapids																																																		
Penford Products Co.																																																		
Cedar Rapids																																																		
Cargill Inc.																																																		
Eddyville																																																		
A. E. Staley Mfg. Co. (Ildorado Decatur																																																		
National Starch & Chemical Co (Indianapolis																																																		

CWM TOXICS

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Hydrogen IFreon 113 Peracetic ACyclohexarkylene Lead CompNickel ComSelenium Vanadium Barium ManganeseNitric Acid Styrene Butadiene AmmoniumN-Butyl AcVinyl AcetaBenzene TrichlorofluToluene Dichlorodifluoromethane

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Bromotrifluoromethane	Lead Comp	Manganese	Butadiene	trichlorofluoromethane
Freon 113	Nickel Comp	Nitric Acid	Ammonium	Toluene
Peracetic Acid	Selenium Comp	Styrene	Vinyl	
Cyclohexanone				
Xylene				

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OPERATOR	UNIT_NAME	STATE	YEAR	COAL (THOUSAND SH TONS)	ASH (%)	E X F
SOUTHERN INDIANA GAS ELEC	AB BROWN 1	IN	1993	470.4	7.96	3744.384
SOUTHERN INDIANA GAS ELEC	AB BROWN 2	IN	1993	391.3	8.09	3165.617
AMES MUNI ELEC SYSTEM	AMES TWO 7	IA	1993	40.1	4.47	179.247
AMES MUNI ELEC SYSTEM	AMES TWO 8	IA	1993	154.5	4.45	687.525
NO INDIANA PUBLIC SERVICE	BAILLY 7	IN	1993	492.8	10.15	5001.92
NO INDIANA PUBLIC SERVICE	BAILLY 8	IN	1993	890.3	10.15	9036.545
ILLINOIS POWER CO	BALDWIN 1	IL	1993	1394.4	9.34	13023.7
ILLINOIS POWER CO	BALDWIN 2	IL	1993	1267.5	9.34	11838.45
ILLINOIS POWER CO	BALDWIN 3	IL	1993	1432.6	9.34	13380.48
INDIANA MICHIGAN POWER CO	BREED 1	IN	1993	17.1	11	188.1
IOWA SOUTHERN UTILITIES	BURLINGTON (IA) 1	IA	1993	468.5	7.8	3654.3
PSI ENERGY INC	CAYUGA 1	IN	1993	1170.3	9.51	11129.55
PSI ENERGY INC	CAYUGA 2	IN	1993	1187.9	9.5	11285.05
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 1	IN	1993	666.8	10.69	7128.092
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 2	IN	1993	693.3	10.69	7411.377
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 3	IN	1993	682.5	10.69	7295.925
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 4	IN	1993	648.1	10.69	6928.189
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 5	IN	1993	575.8	10.69	6155.302
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 6	IN	1993	701	10.69	7493.69
CENT ILLINOIS PUBLIC SERV	COFFEEN 1	IL	1993	523.2	9.39	4912.848
CENT ILLINOIS PUBLIC SERV	COFFEEN 2	IL	1993	1152.3	9.44	10877.71
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS 1	IA	1993	205.2	4.64	952.128
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS 2	IA	1993	305	4.65	1418.25
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS 3	IA	1993	1876.8	4.5	8445.6
COMMONWEALTH EDISON CO	CRAWFORD 7	IL	1993	226.7	5.51	1249.117
COMMONWEALTH EDISON CO	CRAWFORD 8	IL	1993	590.5	5.67	3348.135
CRAWFORDSVILLE ELEC LT PR	CRAWFORDSVILLE 5	IN	1993	11.32	8.19	92.7108
SOUTHERN INDIANA GAS ELEC	CULLEY 1	IN	1993	61	8.33	508.13
SOUTHERN INDIANA GAS ELEC	CULLEY 2	IN	1993	264.6	8.22	2175.012
SOUTHERN INDIANA GAS ELEC	CULLEY 3	IN	1993	784	9.76	7651.84
SPRINGFIELD WTR LT & PWR	DALLMAN 1	IL	1993	192.9	10.09	1946.361
SPRINGFIELD WTR LT & PWR	DALLMAN 2	IL	1993	235.5	10.08	2373.84
SPRINGFIELD WTR LT & PWR	DALLMAN 3	IL	1993	528.6	10.08	5328.288

NO INDIANA PUBLIC SERVICE	DH MITCHELL 11	IN	1993	269.1	5.89	1584.999
NO INDIANA PUBLIC SERVICE	DH MITCHELL 4	IN	1993	107.5	5.82	625.65
NO INDIANA PUBLIC SERVICE	DH MITCHELL 5	IN	1993	259.4	6.13	1590.122
NO INDIANA PUBLIC SERVICE	DH MITCHELL 6	IN	1993	392.1	6.04	2368.284
INTERSTATE POWER CO	DUBUQUE 2	IA	1993	0.9	10.91	9.819
INTERSTATE POWER CO	DUBUQUE 3	IA	1993	25.3	10.91	276.023
INTERSTATE POWER CO	DUBUQUE 4	IA	1993	51.5	10.91	561.865
CENTRAL ILLINOIS LIGHT CO	DUCK CREEK 1	IL	1993	1044.8	8.21	8577.808
CORN BELT POWER COOP	EARL F WISDOM 1	IA	1993	19	9.7	184.3
JASPER MUNICIPAL UTIL	EAST FIFTEENTH ST 1	IN	1993	35.2	9.41	331.232
CENTRAL ILLINOIS LIGHT CO	ED EDWARDS 1	IL	1993	119.8	5.95	712.81
CENTRAL ILLINOIS LIGHT CO	ED EDWARDS 2	IL	1993	462.2	5.96	2754.712
CENTRAL ILLINOIS LIGHT CO	ED EDWARDS 3	IL	1993	612.8	6.4	3921.92
INDIANAPOLIS POWER & LT	EW STOUT 5	IN	1993	223.4	8.11	1811.774
INDIANAPOLIS POWER & LT	EW STOUT 6	IN	1993	180.9	8.11	1467.099
INDIANAPOLIS POWER & LT	EW STOUT 7	IN	1993	805.3	8.14	6555.142
CENTRAL IOWA POWER COOP	FE FAIR 1	IA	1993	42.7	9.48	404.796
CENTRAL IOWA POWER COOP	FE FAIR 2	IA	1993	83.7	9.46	791.802
COMMONWEALTH EDISON CO	FISK 19	IL	1993	598.2	5.14	3074.748
PSI ENERGY INC	GALLAGHER 1	IN	1993	301.77	8.66	2613.328
PSI ENERGY INC	GALLAGHER 2	IN	1993	304.82	8.66	2639.741
PSI ENERGY INC	GALLAGHER 3	IN	1993	262.04	8.63	2261.405
PSI ENERGY INC	GALLAGHER 4	IN	1993	244.9	8.78	2150.222
MIDWEST POWER SYSTEMS	GEORGE NEAL 1	IA	1993	443.3	6.29	2788.357
MIDWEST POWER SYSTEMS	GEORGE NEAL 2	IA	1993	832.6	7.84	6527.584
MIDWEST POWER SYSTEMS	GEORGE NEAL 3	IA	1993	1737.7	5.01	8705.877
MIDWEST POWER SYSTEMS	GEORGE NEAL 4	IA	1993	2581.2	5.12	13215.74
PSI ENERGY INC	GIBSON 1	IN	1993	1703.9	10.18	17345.7
PSI ENERGY INC	GIBSON 2	IN	1993	1325.5	10.06	13334.53
PSI ENERGY INC	GIBSON 3	IN	1993	1751.3	10.18	17828.23
PSI ENERGY INC	GIBSON 4	IN	1993	1612.6	10.18	16416.27
PSI ENERGY INC	GIBSON 5	IN	1993	1628.9	8.62	14041.12
CENT ILLINOIS PUBLIC SERV	GRAND TOWER 3	IL	1993	19.3	11.83	228.319
CENT ILLINOIS PUBLIC SERV	GRAND TOWER 4	IL	1993	132.3	11.76	1555.848

ILLINOIS POWER CO	HAVANA 6	IL	1993	569.7	8.75	4984.875
ILLINOIS POWER CO	HENNEPIN 1	IL	1993	81.8	9.94	813.092
ILLINOIS POWER CO	HENNEPIN 2	IL	1993	462.5	9.93	4592.625
INDIANAPOLIS POWER & LT	HT PRITCHARD 3	IN	1993	28.6	7.51	214.786
INDIANAPOLIS POWER & LT	HT PRITCHARD 4	IN	1993	68.4	7.5	513
INDIANAPOLIS POWER & LT	HT PRITCHARD 5	IN	1993	69.7	7.5	522.75
INDIANAPOLIS POWER & LT	HT PRITCHARD 6	IN	1993	210.6	7.5	1579.5
CENT ILLINOIS PUBLIC SERV	HUTSONVILLE 3	IL	1993	112.1	9.62	1078.402
CENT ILLINOIS PUBLIC SERV	HUTSONVILLE 4	IL	1993	99	9.57	947.43
COMMONWEALTH EDISON CO	JOLIET 6	IL	1993	597.5	4.28	2557.3
COMMONWEALTH EDISON CO	JOLIET 7	IL	1993	1225.3	5.64	6910.692
COMMONWEALTH EDISON CO	JOLIET 8	IL	1993	657.3	5.74	3772.902
ELECTRIC ENERGY INC	JOPPA 1	IL	1993	518.2	7.11	3684.402
ELECTRIC ENERGY INC	JOPPA 2	IL	1993	623.2	7.11	4430.952
ELECTRIC ENERGY INC	JOPPA 3	IL	1993	629.3	7.11	4474.323
ELECTRIC ENERGY INC	JOPPA 4	IL	1993	557.5	7.11	3963.825
ELECTRIC ENERGY INC	JOPPA 5	IL	1993	642	7.11	4564.62
ELECTRIC ENERGY INC	JOPPA 6	IL	1993	672	7.11	4777.92
COMMONWEALTH EDISON CO	KINCAID 1	IL	1993	772.6	9.25	7146.55
COMMONWEALTH EDISON CO	KINCAID 2	IL	1993	1174.3	9.33	10956.22
SPRINGFIELD WTR LT & PWR	LAKESIDE (IL) 6	IL	1993	38.5	10.17	391.545
SPRINGFIELD WTR LT & PWR	LAKESIDE (IL) 7	IL	1993	39.9	10.09	402.591
INTERSTATE POWER CO	LANSING 1	IA	1993	3.6	11.52	41.472
INTERSTATE POWER CO	LANSING 2	IA	1993	3.6	11.52	41.472
INTERSTATE POWER CO	LANSING 3	IA	1993	19.3	11.52	222.336
INTERSTATE POWER CO	LANSING 4	IA	1993	529	4.64	2454.56
LOGANSPOUT MUNI UTIL	LOGANSPOUT 4	IN	1993	33	6.79	224.07
LOGANSPOUT MUNI UTIL	LOGANSPOUT 5	IN	1993	49	6.79	332.71
IOWA-ILLINOIS GAS & ELEC	LOUISA 1	IA	1993	2157.7	4.99	10766.92
SOUTH ILLINOIS POWER COOP	MARION (IL) 1	IL	1993	21	15.52	325.92
SOUTH ILLINOIS POWER COOP	MARION (IL) 2	IL	1993	12	14.28	171.36
SOUTH ILLINOIS POWER COOP	MARION (IL) 3	IL	1993	13	14.61	189.93
SOUTH ILLINOIS POWER COOP	MARION (IL) 4	IL	1993	476	15.49	7373.24
CENT ILLINOIS PUBLIC SERV	MEREDOSIA 1	IL	1993	10.8	6.62	71.496

CENT ILLINOIS PUBLIC SERV	MEREDOSIA 2	IL	1993	13.8	6.59	90.942
CENT ILLINOIS PUBLIC SERV	MEREDOSIA 3	IL	1993	458.4	6.54	2997.936
HOOSIER ENERGY REC	MEROM 1	IN	1993	1184.8	12.01	14229.45
HOOSIER ENERGY REC	MEROM 2	IN	1993	1393.2	11.98	16690.54
NO INDIANA PUBLIC SERVICE	MICHIGAN CITY 12	IN	1993	1373.1	7.76	10655.26
INTERSTATE POWER CO	ML KAPP 2	IA	1993	510.1	7.59	3871.659
MUSCATINE POWER & WATER	MUSCATINE 7	IA	1993	33.5	9.82	328.97
MUSCATINE POWER & WATER	MUSCATINE 8	IA	1993	80.6	10	806
MUSCATINE POWER & WATER	MUSCATINE 9	IA	1993	537.3	6.65	3573.045
CENT ILLINOIS PUBLIC SERV	NEWTON 1	IL	1993	1195.2	11.01	13159.15
CENT ILLINOIS PUBLIC SERV	NEWTON 2	IL	1993	1360	9.27	12607.2
IOWA SOUTHERN UTILITIES	OTTUMWA 1	IA	1993	2676.1	5.31	14210.09
SOYLAND POWER COOP	PEARL 1	IL	1993	62.8	8.17	513.076
PERU (IN) UTILITIES	PERU (IN) 2	IN	1993	1.18	9.37	11.0566
INDIANAPOLIS POWER & LT	PETERSBURG 1	IN	1993	710.9	8.64	6142.176
INDIANAPOLIS POWER & LT	PETERSBURG 2	IN	1993	1154.4	8.72	10066.37
INDIANAPOLIS POWER & LT	PETERSBURG 3	IN	1993	1456.7	8.64	12585.89
INDIANAPOLIS POWER & LT	PETERSBURG 4	IN	1993	1292.6	8.64	11168.06
COMMONWEALTH EDISON CO	POWERTON 5	IL	1993	1161.9	4.79	5565.501
COMMONWEALTH EDISON CO	POWERTON 6	IL	1993	1733.4	4.88	8458.992
IOWA ELEC LIGHT & POWER	PRAIRIE CREEK 3	IA	1993	112.6	5.7	641.82
IOWA ELEC LIGHT & POWER	PRAIRIE CREEK 4	IA	1993	417.9	5.7	2382.03
HOOSIER ENERGY REC	RATTS 1	IN	1993	266.4	9.42	2509.488
HOOSIER ENERGY REC	RATTS 2	IN	1993	320.4	9.43	3021.372
IOWA-ILLINOIS GAS & ELEC	RIVERSIDE (IA) 5	IA	1993	152.4	9.26	1411.224
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 14	IN	1993	959.3	7.24	6945.332
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 15	IN	1993	938.3	8.25	7740.975
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 17	IN	1993	705.6	10.12	7140.672
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 18	IN	1993	694.9	10.21	7094.929
INDIANA MICHIGAN POWER CO	ROCKPORT 1	IN	1993	4718.8	4.81	22697.43
INDIANA MICHIGAN POWER CO	ROCKPORT 2	IN	1993	4842.8	4.86	23536.01
COMMONWEALTH EDISON (IN)	STATE LINE 3	IN	1993	384.3	3.59	1379.637
COMMONWEALTH EDISON (IN)	STATE LINE 4	IN	1993	406.4	4.4	1788.16
CEDAR FALLS UTILITIES	STREETER 6	IA	1993	1.6	8.4	13.44

CEDAR FALLS UTILITIES	STREETER 7	IA	1993	23.2	8.55	198.36
IOWA ELEC LIGHT & POWER	SUTHERLAND 1	IA	1993	69.9	4.07	284.493
IOWA ELEC LIGHT & POWER	SUTHERLAND 2	IA	1993	73.2	4.07	297.924
IOWA ELEC LIGHT & POWER	SUTHERLAND 3	IA	1993	215.5	4.07	877.085
INDIANA MICHIGAN POWER CO	TANNERS CREEK 1	IN	1993	283.6	10.36	2938.096
INDIANA MICHIGAN POWER CO	TANNERS CREEK 2	IN	1993	92.9	9.98	927.142
INDIANA MICHIGAN POWER CO	TANNERS CREEK 3	IN	1993	164.4	10.48	1722.912
INDIANA MICHIGAN POWER CO	TANNERS CREEK 4	IN	1993	1322.1	9.39	12414.52
ILLINOIS POWER CO	VERMILION 1	IL	1993	111.2	11.8	1312.16
ILLINOIS POWER CO	VERMILION 2	IL	1993	211.6	11.73	2482.068
PSI ENERGY INC	WABASH RIVER 1	IN	1993	147.9	9.07	1341.453
PSI ENERGY INC	WABASH RIVER 2	IN	1993	170.8	9.06	1547.448
PSI ENERGY INC	WABASH RIVER 3	IN	1993	175.38	9.07	1590.697
PSI ENERGY INC	WABASH RIVER 4	IN	1993	143.18	9.07	1298.643
PSI ENERGY INC	WABASH RIVER 5	IN	1993	178.41	9.07	1618.179
PSI ENERGY INC	WABASH RIVER 6	IN	1993	593.35	9.07	5381.685
SOUTHERN INDIANA GAS ELEC	WARRICK 4	IN	1993	993.3	9.76	9694.608
COMMONWEALTH EDISON CO	WAUKEGAN 6	IL	1993	181.4	4.81	872.534
COMMONWEALTH EDISON CO	WAUKEGAN 7	IL	1993	740.7	5.31	3933.117
COMMONWEALTH EDISON CO	WAUKEGAN 8	IL	1993	390.4	5.66	2209.664
RICHMOND POWER & LIGHT	WHITEWATER VALLEY 1IN	IN	1993	94.2	9.81	924.102
RICHMOND POWER & LIGHT	WHITEWATER VALLEY 2IN	IN	1993	202	9.81	1981.62
COMMONWEALTH EDISON CO	WILL COUNTY 1	IL	1993	415	4.88	2025.2
COMMONWEALTH EDISON CO	WILL COUNTY 2	IL	1993	458.2	4.57	2093.974
COMMONWEALTH EDISON CO	WILL COUNTY 3	IL	1993	542.5	5.09	2761.325
COMMONWEALTH EDISON CO	WILL COUNTY 4	IL	1993	1069.8	5.15	5509.47
ILLINOIS POWER CO	WOOD RIVER (IL) 4	IL	1993	87.4	8.16	713.184
ILLINOIS POWER CO	WOOD RIVER (IL) 5	IL	1993	683.1	8.22	5615.082
TOTAL				96843.05	1353.45	745361
AVERAGE					8.303374233	
WT. AVERAGE					7.696587462	

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OPERATOR	UNIT_NAME	STATE	YEAR	COAL (THOUSAND SH TONS)	SULFUR (%)	E X F
SOUTHERN INDIANA GAS ELECTRIC	BROWN 1	IN	1993	470.4	3.67	1726.368
SOUTHERN INDIANA GAS ELECTRIC	BROWN 2	IN	1993	391.3	3.69	1443.897
AMES MUNI ELEC SYSTEM	AMES TWO 7	IA	1993	40.1	0.21	8.421
AMES MUNI ELEC SYSTEM	AMES TWO 8	IA	1993	154.5	0.21	32.445
NO INDIANA PUBLIC SERVICE	BAILLY 7	IN	1993	492.8	3	1478.4
NO INDIANA PUBLIC SERVICE	BAILLY 8	IN	1993	890.3	2.97	2644.191
ILLINOIS POWER CO	BALDWIN 1	IL	1993	1394.4	2.58	3597.552
ILLINOIS POWER CO	BALDWIN 2	IL	1993	1267.5	2.58	3270.15
ILLINOIS POWER CO	BALDWIN 3	IL	1993	1432.6	2.58	3696.108
INDIANA MICHIGAN POWER CORP	BREED 1	IN	1993	17.1	3.66	62.586
IOWA SOUTHERN UTILITIES	BURLINGTON (IA)	IA	1993	468.5	1.48	693.38
PSI ENERGY INC	CAYUGA 1	IN	1993	1170.3	2.1	2457.63
PSI ENERGY INC	CAYUGA 2	IN	1993	1187.9	2.11	2506.469
INDIANA KENTUCKY ELECTRIC	CORCLIFTY CREEK 1	IN	1993	666.8	3.28	2187.104
INDIANA KENTUCKY ELECTRIC	CORCLIFTY CREEK 2	IN	1993	693.3	3.28	2274.024
INDIANA KENTUCKY ELECTRIC	CORCLIFTY CREEK 3	IN	1993	682.5	3.28	2238.6
INDIANA KENTUCKY ELECTRIC	CORCLIFTY CREEK 4	IN	1993	648.1	3.28	2125.768
INDIANA KENTUCKY ELECTRIC	CORCLIFTY CREEK 5	IN	1993	575.8	3.28	1888.624
INDIANA KENTUCKY ELECTRIC	CORCLIFTY CREEK 6	IN	1993	701	3.28	2299.28
CENT ILLINOIS PUBLIC SERVICE	COFFEEN 1	IL	1993	523.2	2.86	1496.352
CENT ILLINOIS PUBLIC SERVICE	COFFEEN 2	IL	1993	1152.3	2.84	3272.532
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS IA	IA	1993	205.2	0.31	63.612
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS IA	IA	1993	305	0.31	94.55
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS IA	IA	1993	1876.8	0.32	600.576
COMMONWEALTH EDISON CO	CRAWFORD 7	IL	1993	226.7	0.43	97.481
COMMONWEALTH EDISON CO	CRAWFORD 8	IL	1993	590.5	0.42	248.01
CRAWFORDSVILLE ELECTRIC	LT P CRAWFORDSVILL	IN	1993	11.32	1.66	18.7912
SOUTHERN INDIANA GAS ELECTRIC	CULLEY 1	IN	1993	61	1.35	82.35
SOUTHERN INDIANA GAS ELECTRIC	CULLEY 2	IN	1993	264.6	1.35	357.21
SOUTHERN INDIANA GAS ELECTRIC	CULLEY 3	IN	1993	784	2.37	1858.08
SPRINGFIELD WTR LT & PWR	DALLMAN 1	IL	1993	192.9	3.17	611.493
SPRINGFIELD WTR LT & PWR	DALLMAN 2	IL	1993	235.5	3.19	751.245

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SPRINGFIELD WTR LT & PWR DALLMAN 3	IL	1993	528.6	3.19	1686.234
NO INDIANA PUBLIC SERVICE DH MITCHELL 11	IN	1993	269.1	0.39	104.949
NO INDIANA PUBLIC SERVICE DH MITCHELL 4	IN	1993	107.5	0.38	40.85
NO INDIANA PUBLIC SERVICE DH MITCHELL 5	IN	1993	259.4	0.4	103.76
NO INDIANA PUBLIC SERVICE DH MITCHELL 6	IN	1993	392.1	0.39	152.919
INTERSTATE POWER CO DUBUQUE 2	IA	1993	0.9	2.8	2.52
INTERSTATE POWER CO DUBUQUE 3	IA	1993	25.3	2.8	70.84
INTERSTATE POWER CO DUBUQUE 4	IA	1993	51.5	2.8	144.2
CENTRAL ILLINOIS LIGHT CO DUCK CREEK 1	IL	1993	1044.8	3.3	3447.84
CORN BELT POWER COOP EARL F WISDOM 11A	IA	1993	19	2.75	52.25
JASPER MUNICIPAL UTIL EAST FIFTEENTH	IN	1993	35.2	1.39	48.928
CENTRAL ILLINOIS LIGHT CO ED EDWARDS 1	IL	1993	119.8	1.03	123.394
CENTRAL ILLINOIS LIGHT CO ED EDWARDS 2	IL	1993	462.2	1.03	476.066
CENTRAL ILLINOIS LIGHT CO ED EDWARDS 3	IL	1993	612.8	1.03	631.184
INDIANAPOLIS POWER & LT EW STOUT 5	IN	1993	223.4	1.77	395.418
INDIANAPOLIS POWER & LT EW STOUT 6	IN	1993	180.9	1.77	320.193
INDIANAPOLIS POWER & LT EW STOUT 7	IN	1993	805.3	1.77	1425.381
CENTRAL IOWA POWER COOPFE FAIR 1	IA	1993	42.7	3.14	134.078
CENTRAL IOWA POWER COOPFE FAIR 2	IA	1993	83.7	3.16	264.492
COMMONWEALTH EDISON COFISK 19	IL	1993	598.2	0.43	257.226
PSI ENERGY INC GALLAGHER 1	IN	1993	301.77	2.18	657.8586
PSI ENERGY INC GALLAGHER 2	IN	1993	304.82	2.18	664.5076
PSI ENERGY INC GALLAGHER 3	IN	1993	262.04	2.18	571.2472
PSI ENERGY INC GALLAGHER 4	IN	1993	244.9	2.14	524.086
MIDWEST POWER SYSTEMS GEORGE NEAL 1	IA	1993	443.3	0.43	190.619
MIDWEST POWER SYSTEMS GEORGE NEAL 2	IA	1993	832.6	0.47	391.322
MIDWEST POWER SYSTEMS GEORGE NEAL 3	IA	1993	1737.7	0.41	712.457
MIDWEST POWER SYSTEMS GEORGE NEAL 4	IA	1993	2581.2	0.39	1006.668
PSI ENERGY INC GIBSON 1	IN	1993	1703.9	1.43	2436.577
PSI ENERGY INC GIBSON 2	IN	1993	1325.5	1.42	1882.21
PSI ENERGY INC GIBSON 3	IN	1993	1751.3	1.43	2504.359
PSI ENERGY INC GIBSON 4	IN	1993	1612.6	1.43	2306.018
PSI ENERGY INC GIBSON 5	IN	1993	1628.9	2.89	4707.521

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CENT ILLINOIS PUBLIC SERV	GRAND TOWER 3 IL	1993	19.3	2.81	54.233
CENT ILLINOIS PUBLIC SERV	GRAND TOWER 4 IL	1993	132.3	2.81	371.763
ILLINOIS POWER CO	HAVANA 6 IL	1993	569.7	0.6	341.82
ILLINOIS POWER CO	HENNEPIN 1 IL	1993	81.8	2.64	215.952
ILLINOIS POWER CO	HENNEPIN 2 IL	1993	462.5	2.64	1221
INDIANAPOLIS POWER & LT	HT PRITCHARD 3 IN	1993	28.6	1.26	36.036
INDIANAPOLIS POWER & LT	HT PRITCHARD 4 IN	1993	68.4	1.26	86.184
INDIANAPOLIS POWER & LT	HT PRITCHARD 5 IN	1993	69.7	1.26	87.822
INDIANAPOLIS POWER & LT	HT PRITCHARD 6 IN	1993	210.6	1.26	265.356
CENT ILLINOIS PUBLIC SERV	HUTSONVILLE 3 IL	1993	112.1	2.19	245.499
CENT ILLINOIS PUBLIC SERV	HUTSONVILLE 4 IL	1993	99	2.19	216.81
COMMONWEALTH EDISON CO	COJOLIET 6 IL	1993	597.5	0.38	227.05
COMMONWEALTH EDISON CO	COJOLIET 7 IL	1993	1225.3	0.47	575.891
COMMONWEALTH EDISON CO	COJOLIET 8 IL	1993	657.3	0.4	262.92
ELECTRIC ENERGY INC	JOPPA 1 IL	1993	518.2	1.27	658.114
ELECTRIC ENERGY INC	JOPPA 2 IL	1993	623.2	1.27	791.464
ELECTRIC ENERGY INC	JOPPA 3 IL	1993	629.3	1.27	799.211
ELECTRIC ENERGY INC	JOPPA 4 IL	1993	557.5	1.27	708.025
ELECTRIC ENERGY INC	JOPPA 5 IL	1993	642	1.27	815.34
ELECTRIC ENERGY INC	JOPPA 6 IL	1993	672	1.27	853.44
COMMONWEALTH EDISON CO	KINCAID 1 IL	1993	772.6	3.72	2874.072
COMMONWEALTH EDISON CO	KINCAID 2 IL	1993	1174.3	3.7	4344.91
SPRINGFIELD WTR LT & PWR	LAKESIDE (IL) 6 IL	1993	38.5	3.22	123.97
SPRINGFIELD WTR LT & PWR	LAKESIDE (IL) 7 IL	1993	39.9	3.21	128.079
INTERSTATE POWER CO	LANSING 1 IA	1993	3.6	2.27	8.172
INTERSTATE POWER CO	LANSING 2 IA	1993	3.6	2.27	8.172
INTERSTATE POWER CO	LANSING 3 IA	1993	19.3	2.27	43.811
INTERSTATE POWER CO	LANSING 4 IA	1993	529	0.34	179.86
LOGANSPOUT MUNI UTIL	LOGANSPOUT 4 IN	1993	33	0.77	25.41
LOGANSPOUT MUNI UTIL	LOGANSPOUT 5 IN	1993	49	0.77	37.73
IOWA-ILLINOIS GAS & ELEC	LOUISA 1 IA	1993	2157.7	0.34	733.618
SOUTH ILLINOIS POWER CO	COORMARION (IL) 1 IL	1993	21	2.55	53.55
SOUTH ILLINOIS POWER CO	COORMARION (IL) 2 IL	1993	12	2.52	30.24

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SOUTH ILLINOIS POWER COORMARION (IL) 3	IL	1993	13	2.57	33.41
SOUTH ILLINOIS POWER COORMARION (IL) 4	IL	1993	476	2.63	1251.88
CENT ILLINOIS PUBLIC SERV MEREDOSIA 1	IL	1993	10.8	2.97	32.076
CENT ILLINOIS PUBLIC SERV MEREDOSIA 2	IL	1993	13.8	2.96	40.848
CENT ILLINOIS PUBLIC SERV MEREDOSIA 3	IL	1993	458.4	2.99	1370.616
HOOSIER ENERGY REC MEROM 1	IN	1993	1184.8	3.43	4063.864
HOOSIER ENERGY REC MEROM 2	IN	1993	1393.2	3.45	4806.54
NO INDIANA PUBLIC SERVICE MICHIGAN CITY 12IN	IN	1993	1373.1	1.59	2183.229
INTERSTATE POWER CO ML KAPP 2	IA	1993	510.1	1.97	1004.897
MUSCATINE POWER & WATERMUSCATINE 7	IA	1993	33.5	2.81	94.135
MUSCATINE POWER & WATERMUSCATINE 8	IA	1993	80.6	2.78	224.068
MUSCATINE POWER & WATERMUSCATINE 9	IA	1993	537.3	1.47	789.831
CENT ILLINOIS PUBLIC SERV NEWTON 1	IL	1993	1195.2	2.64	3155.328
CENT ILLINOIS PUBLIC SERV NEWTON 2	IL	1993	1360	0.54	734.4
IOWA SOUTHERN UTILITIES OTTUMWA 1	IA	1993	2676.1	0.35	936.635
SOYLAND POWER COOP PEARL 1	IL	1993	62.8	3.18	199.704
PERU (IN) UTILITIES PERU (IN) 2	IN	1993	1.18	2.28	2.6904
INDIANAPOLIS POWER & LT PETERSBURG 1	IN	1993	710.9	2.5	1777.25
INDIANAPOLIS POWER & LT PETERSBURG 2	IN	1993	1154.4	2.5	2886
INDIANAPOLIS POWER & LT PETERSBURG 3	IN	1993	1456.7	2.5	3641.75
INDIANAPOLIS POWER & LT PETERSBURG 4	IN	1993	1292.6	2.5	3231.5
COMMONWEALTH EDISON COPOWERTON 5	IL	1993	1161.9	0.32	371.808
COMMONWEALTH EDISON COPOWERTON 6	IL	1993	1733.4	0.31	537.354
IOWA ELEC LIGHT & POWER PRAIRIE CREEK 3 IA	IA	1993	112.6	0.72	81.072
IOWA ELEC LIGHT & POWER PRAIRIE CREEK 4 IA	IA	1993	417.9	0.72	300.888
HOOSIER ENERGY REC RATTS 1	IN	1993	266.4	3.03	807.192
HOOSIER ENERGY REC RATTS 2	IN	1993	320.4	2.94	941.976
IOWA-ILLINOIS GAS & ELEC RIVERSIDE (IA) 5 IA	IA	1993	152.4	2.3	350.52
NO INDIANA PUBLIC SERVICE RM SCHAHFER 14IN	IN	1993	959.3	0.51	489.243
NO INDIANA PUBLIC SERVICE RM SCHAHFER 15IN	IN	1993	938.3	0.4	375.32
NO INDIANA PUBLIC SERVICE RM SCHAHFER 17IN	IN	1993	705.6	2.91	2053.296
NO INDIANA PUBLIC SERVICE RM SCHAHFER 18IN	IN	1993	694.9	2.93	2036.057
INDIANA MICHIGAN POWER COORCKPORT 1	IN	1993	4718.8	0.31	1462.828

INDIANA MICHIGAN POWER CORPORATION 2	IN	1993	4842.8	0.31	1501.268
COMMONWEALTH EDISON (IN STATE LINE 3	IN	1993	384.3	0.38	146.034
COMMONWEALTH EDISON (IN STATE LINE 4	IN	1993	406.4	0.4	162.56
CEDAR FALLS UTILITIES STREETER 6	IA	1993	1.6	2.77	4.432
CEDAR FALLS UTILITIES STREETER 7	IA	1993	23.2	2.09	48.488
IOWA ELEC LIGHT & POWER SUTHERLAND 1	IA	1993	69.9	1.01	70.599
IOWA ELEC LIGHT & POWER SUTHERLAND 2	IA	1993	73.2	1.01	73.932
IOWA ELEC LIGHT & POWER SUTHERLAND 3	IA	1993	215.5	1.01	217.655
INDIANA MICHIGAN POWER CORPORATION CREEK IN	IN	1993	283.6	0.69	195.684
INDIANA MICHIGAN POWER CORPORATION CREEK IN	IN	1993	92.9	0.7	65.03
INDIANA MICHIGAN POWER CORPORATION CREEK IN	IN	1993	164.4	0.7	115.08
INDIANA MICHIGAN POWER CORPORATION CREEK IN	IN	1993	1322.1	2.38	3146.598
ILLINOIS POWER CO VERMILION 1	IL	1993	111.2	2.22	246.864
ILLINOIS POWER CO VERMILION 2	IL	1993	211.6	2.21	467.636
PSI ENERGY INC WABASH RIVER 1 IN	IN	1993	147.9	2.02	298.758
PSI ENERGY INC WABASH RIVER 2 IN	IN	1993	170.8	2.03	346.724
PSI ENERGY INC WABASH RIVER 3 IN	IN	1993	175.38	2.02	354.2676
PSI ENERGY INC WABASH RIVER 4 IN	IN	1993	143.18	2.02	289.2236
PSI ENERGY INC WABASH RIVER 5 IN	IN	1993	178.41	2.02	360.3882
PSI ENERGY INC WABASH RIVER 6 IN	IN	1993	593.35	2.02	1198.567
SOUTHERN INDIANA GAS ELECTRIC 4	IN	1993	993.3	2.58	2562.714
COMMONWEALTH EDISON CO WAUKEGAN 6	IL	1993	181.4	0.35	63.49
COMMONWEALTH EDISON CO WAUKEGAN 7	IL	1993	740.7	0.37	274.059
COMMONWEALTH EDISON CO WAUKEGAN 8	IL	1993	390.4	0.37	144.448
RICHMOND POWER & LIGHT WHITEWATER VALLEY	VA	1993	94.2	2.03	191.226
RICHMOND POWER & LIGHT WHITEWATER VALLEY	VA	1993	202	2.03	410.06
COMMONWEALTH EDISON CO WILL COUNTY 1	IL	1993	415	0.31	128.65
COMMONWEALTH EDISON CO WILL COUNTY 2	IL	1993	458.2	0.31	142.042
COMMONWEALTH EDISON CO WILL COUNTY 3	IL	1993	542.5	0.33	179.025
COMMONWEALTH EDISON CO WILL COUNTY 4	IL	1993	1069.8	0.32	342.336
ILLINOIS POWER CO WOOD RIVER (IL)	IL	1993	87.4	0.68	59.432
ILLINOIS POWER CO WOOD RIVER (IL)	IL	1993	683.1	0.69	471.339

CWM Sulfur

TOTAL	291.93	148593.7904
AVERAGE	1.79	
WT. AVERAGE	1.53	

96843.05

Sheet Title:

Acetonitrile and acrylonitrile production

Sheet Description:

Emissions are from TRI database.
Engineering calculation of the Energy requirements and precursor requirements .
This page calculates the vendor emissions from a plant producing PCI3.
Not included are raw material production or extraction or water use.

References/Citations:

Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Source:

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

Acetonitrile

Mwt	Co-product	Quantity	Units	Quantity	Units	1993 Production
53.06	Acetonitrile	1.58E-02 kg		1.00E+00 kg		17,859.00
41.0524	Acrylonitrile	1.00E+00 kg		6.32E+01 kg		1,129,082.00
27.0256	HCN to Acetone cyanoh	2.12E-01 kg		1.34E+01 kg		239,876.00
	Total	1.23 Kg		7.77E+01 Kg		1,240,744.98

As acetone cyanoh

Notes:

LCI components		Unallocated		Allocated	
		Units	Quantity	Std. Dev.	Units
Air					Quantity
Cl2		Kg/kg Acrylonitrile	1.63642E-06		Kg/kg Acetonit
Acetonitrile		Kg/kg Acrylonitrile	7.67072E-06		Kg/kg Acetonit
Acrolein		Kg/kg Acrylonitrile	1.50005E-07		Kg/kg Acetonit
Acrylic acid		Kg/kg Acrylonitrile	5.11381E-09		Kg/kg Acetonit
Acrylonitrile		Kg/kg Acrylonitrile	5.52292E-05		Kg/kg Acetonit
ammonia		Kg/kg Acrylonitrile	1.44891E-05		Kg/kg Acetonit
Hydrogen Cyanide		Kg/kg Acrylonitrile	8.21619E-05		Kg/kg Acetonit
Propylene		Kg/kg Acrylonitrile	2.82964E-05		Kg/kg Acetonit
acetamide		Kg/kg Acrylonitrile	1.7046E-08		Kg/kg Acetonit
acetaldehyde		Kg/kg Acrylonitrile	6.64795E-08		Kg/kg Acetonit
Acrylamide		Kg/kg Acrylonitrile	3.80127E-07		Kg/kg Acetonit
Pyridine		Kg/kg Acrylonitrile	2.591E-07		Kg/kg Acetonit
HC total		Kg/kg Acrylonitrile	0.000188725		Kg/kg Acetonit
Water					
ammonia		Kg/kg Acrylonitrile	4.94335E-07		Kg/kg Acetonit
Solid Wastes					
Acetonitrile		Kg/kg Acrylonitrile	5.11381E-09		Kg/kg Acetonit
Acrylonitrile		Kg/kg Acrylonitrile	8.52302E-09		Kg/kg Acetonit

Acetonitrile

Shipped out

Total	Kg/kg Acrylonitrile	3.74655E-05	Kg/kg Acetonit	3.05027E-05
Acetonitrile	Kg/kg Acrylonitrile	5.79565E-07	Kg/kg Acetonit	4.71855E-07
Acrolein	Kg/kg Acrylonitrile	1.36368E-08	Kg/kg Acetonit	1.11025E-08
Acrylic acid	Kg/kg Acrylonitrile	2.04552E-07	Kg/kg Acetonit	1.66537E-07
Acrylonitrile	Kg/kg Acrylonitrile	6.30703E-08	Kg/kg Acetonit	5.13489E-08
ammonia	Kg/kg Acrylonitrile	3.57967E-05	Kg/kg Acetonit	2.9144E-05
Molybdenum Trioxide	Kg/kg Acrylonitrile	3.23875E-05	Kg/kg Acetonit	2.63684E-05
acetamide	Kg/kg Acrylonitrile	1.67051E-07	Kg/kg Acetonit	1.36005E-07
acetaldehyde	Kg/kg Acrylonitrile	2.55691E-08	Kg/kg Acetonit	2.08171E-08
Acrylamide	Kg/kg Acrylonitrile	5.96611E-07	Kg/kg Acetonit	4.85733E-07
Pyridine	Kg/kg Acrylonitrile	1.87506E-08	Kg/kg Acetonit	1.52659E-08
LCI component	Kg/kg Acrylonitrile	0.006477494	Kg/kg Acetonit	0.005273675
Acetonitrile	Kg/kg Acrylonitrile	7.84118E-08	Kg/kg Acetonit	6.38392E-08
Acrolein	Kg/kg Acrylonitrile	0.000272737	Kg/kg Acetonit	0.000222049
Acrylic acid	Kg/kg Acrylonitrile	0.001056854	Kg/kg Acetonit	0.000860442
Acrylonitrile	Kg/kg Acrylonitrile	0.023864452	Kg/kg Acetonit	0.019429329
Propylene	Kg/kg Acrylonitrile	9.37532E-05	Kg/kg Acetonit	7.63295E-05
Molybdenum Trioxide	Kg/kg Acrylonitrile	0.00015171	Kg/kg Acetonit	0.000123515
acetamide	Kg/kg Acrylonitrile	1.00572E-05	Kg/kg Acetonit	8.18807E-06
acetaldehyde	Kg/kg Acrylonitrile	0.001585281	Kg/kg Acetonit	0.001290663
Acrylamide	Kg/kg Acrylonitrile	0.000136368	Kg/kg Acetonit	0.000111025

Resource Consumption

Heat Energy (fossil fuel)	MJ/kg Acrylonitrile	1.100482758	MJ/kg Acetonit	0.895961957
Electric Power	MJ/kg Acrylonitrile	5.78119E-07	MJ/kg Acetonit	4.70677E-07
ammonia	Kg/kg Acrylonitrile	0.475	Kg/kg Acetonit	0.386722942
propylene	Kg/kg Acrylonitrile	1.175	Kg/kg Acetonit	0.956630435

Notes: This section is where the project specific calculations take place. Information on LCI components from below is co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the c rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was

Conversion Factors

Unit from	Unit to	Multiplier	Reference
BTU	J	1055.056	CRC, 66th Edition
Wh	J	3600	CRC, 66th Edition
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76
gal	L	3.785412	CRC, 66th Edition
kg	lb	2.2046226	CRC, 66th Edition
yr	day	365	
m ³	bbl (petroleum)	6.289811	CRC, 66th Edition
gal CrO	lb CrO	7.2	
ton	lb	2000	
gal fuel oil	BTU fuel oil	138000	
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.
lb Coal (dry)	BTU Coal	12000	calculation page B SD=11%
kg NG	MJ NG	46	Calculated page C SD=13%

Mw Benzen	78.1134	molar	
Mw Chlorin	70.9	dry air composition	
Mw ClBz	112.56	N2	0.78084 28.0134 0.75521
Mw Cl2Bz	147.01	O2	0.20946 31.9988 0.231406
Mw HCl	36.4609	CO2	0.00033 44.01 0.000501
Mw NaOH	39.9971	Ar	0.00934 39.948 0.012882
		total	0.99997 28.96409 1

Ideal gas density at 15 C (60 F)	air (dry)
0.042296 mol/liter	42.29634021 mol/m ³ 1.225075005 kg/m ³

Calculations

Acrylonitrile (and acetonitrile) Production

1993

Source:

US Chemical Industry Statistical Handbook 1994
Chemical Manufacturers Association, Washington DC

m ton 1,129,082.00 Milb 2489.174177

MEK production capacity

Source: SRI 1991 Directory of Chemical Producers, US
Milb

3055

Utilization ratio:

0.814786965

BP Chemicals, Inc. Green Lake @ RMlb
at Port Lavaca TX 77979

720

Calculated production:

586.6466146

Source:

Emissions:

TRI database, 1993 data

The Green Lake plant of BP produces acrylonitrile from propylene and some by products including hydrogen cyanide.

The following reported emissions were deemed unrelated to 'nitrile production:

Emissions allocated between the products =

Acetone diethanolamine
Acetonitrile Acrolein

Co-Products:

Given above.

Resources:

Energy input

LCI component

Fossil fuel (general)

Coal

Oil

Natural Gas

Hydropower

Fission

Electricity (generic)

Energy requirement

Raw/
Input Units

MJ/kg Acrylonitrile

MJ/kg Acrylonitrile

MJ/kg Acrylonitrile

MJ/kg Acrylonitrile

MJ/kg Acrylonitrile

MJ/kg Acrylonitrile

MJ/kg Acrylonitrile

Raw/
Input Quan.

1.100482758

0

0

0

0

0

0

Raw/
Input Std. Dev.

15

DQI

Transformed
Units

MJ/Kg Acrylonitrile

Kg/kg Acrylonitrile

Kg/kg Acrylonitrile

Kg/kg Acrylonitrile

MJ/Kg Acrylonitrile

Heat	Distillation columns	3 prod is light end 1 bottoms product	Evaporate acrylonitrile once Evaporate acetonitrile twice 10% loss as bottoms	Cal/mol	7941.4 16348.4 794.14
			cal/gr	MJ/Kg	
			Cooling water	25	0.1027
			Coolers: flow	General flow	
			Kg	Kg/Kg Acrylonitrile	
Electricity	9 minimum pumping stations + 4 coolers	Pump 1 Kg	2.67887721 Acrylonitrile	1.00E+00	
			Acetonitrile	1.58E-02	
			HCN/Acetonitri	0.456539029	

source:

Material input

LCI component	Raw/ Input Units	Raw/		Transformed Units
		Input Quan.	Input Std. Dev.	
Oil	Kg/kg Acrylonitrile	0		4 Kg/kg Acrylonitrile
Natural Gas	Kg/kg Acrylonitrile	0		4 Kg/kg Acrylonitrile
Coal	Kg/kg Acrylonitrile	0		4 Kg/kg Acrylonitrile
Naphtha	Kg/kg Acrylonitrile	0		4 Kg/kg Acrylonitrile
ammonia	Kg/kg Acrylonitrile	0.475		4 Kg/kg Acrylonitrile
propylene	Kg/kg Acrylonitrile	1.175		4 Kg/kg Acrylonitrile
Air	Kg/kg Acrylonitrile	0		4 Kg/kg Acrylonitrile
Water	Kg/kg Acrylonitrile	0		4 Kg/kg Acrylonitrile
steam	Kg/kg Acrylonitrile	0		4 Kg/kg Acrylonitrile

Air

Acetonitrile

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units
TSP	lb/BP Green Lake	0			Kg/kg Acrylonitrile
SOx	lb/BP Green Lake	0			Kg/kg Acrylonitrile
NOx	lb/BP Green Lake	0			Kg/kg Acrylonitrile
Cl2	lb/BP Green Lake	960			Kg/kg Acrylonitrile
CO2	lb/BP Green Lake	0			3 Kg/kg Acrylonitrile
P4	lb/BP Green Lake	0			Kg/kg Acrylonitrile
Acetonitrile	lb/BP Green Lake	4500			Kg/kg Acrylonitrile
Acrolein	lb/BP Green Lake	88			Kg/kg Acrylonitrile
Acrylic acid	lb/BP Green Lake	3			Kg/kg Acrylonitrile
Acrylonitrile	lb/BP Green Lake	32400			Kg/kg Acrylonitrile
ammonia	lb/BP Green Lake	8500			Kg/kg Acrylonitrile
Hydrogen Cyanide	lb/BP Green Lake	48200			Kg/kg Acrylonitrile
Propylene	lb/BP Green Lake	16600			Kg/kg Acrylonitrile
Molybdenum Trioxide	lb/BP Green Lake	0			Kg/kg Acrylonitrile
acetamide	lb/BP Green Lake	10			Kg/kg Acrylonitrile
acetaldehyde	lb/BP Green Lake	39			Kg/kg Acrylonitrile
Acrylamide	lb/BP Green Lake	223			Kg/kg Acrylonitrile
Pyridine	lb/BP Green Lake	152			Kg/kg Acrylonitrile
HC total	lb/BP Green Lake	110715			Kg/kg Acrylonitrile
Heavy meta(Cd+Ni+Cr)	lb/BP Green Lake	0			Kg/kg Acrylonitrile

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units
COD	lb/BP Green Lake	0			5 Kg/kg Acrylonitrile
BOD	lb/BP Green Lake	0			5 Kg/kg Acrylonitrile
Acid, H+ (Phosphoric)	lb/BP Green Lake	0			5 Kg/kg Acrylonitrile
Metal ions	lb/BP Green Lake	0			5 Kg/kg Acrylonitrile
Cl2	lb/BP Green Lake	0			5 Kg/kg Acrylonitrile
Acetonitrile	lb/BP Green Lake	0			5 Kg/kg Acrylonitrile

Acetonitrile

Acrolein	lb/BP Green Lake	0	5 Kg/kg Acrylonitrile
Acrylic acid	lb/BP Green Lake	0	5 Kg/kg Acrylonitrile
Acrylonitrile	lb/BP Green Lake	0	5 Kg/kg Acrylonitrile
ammonia	lb/BP Green Lake	290	5 Kg/kg Acrylonitrile
Hydrogen Cyanide	lb/BP Green Lake	0	Kg/kg Acrylonitrile
Propylene	lb/BP Green Lake	0	Kg/kg Acrylonitrile
Molybdenum Trioxide	lb/BP Green Lake	0	Kg/kg Acrylonitrile
acetamide	lb/BP Green Lake	0	Kg/kg Acrylonitrile
acetaldehyde	lb/BP Green Lake	0	Kg/kg Acrylonitrile
Acrylamide	lb/BP Green Lake	0	Kg/kg Acrylonitrile
Pyridine	lb/BP Green Lake	0	Kg/kg Acrylonitrile

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units
Production waste (not inert)	lb/BP Green Lake	0			5 Kg/kg Acrylonitrile
Acetonitrile	lb/BP Green Lake	3			Kg/kg Acrylonitrile
Acrylonitrile	lb/BP Green Lake	5			5 Kg/kg Acrylonitrile
Shipped out total no catalyst	lb/BP Green Lake	21979			5 Kg/kg Acrylonitrile
Acetonitrile	lb/BP Green Lake	340			5 Kg/kg Acrylonitrile
Acrolein	lb/BP Green Lake	8			5 Kg/kg Acrylonitrile
Acrylic acid	lb/BP Green Lake	120			5 Kg/kg Acrylonitrile
Acrylonitrile	lb/BP Green Lake	37			5 Kg/kg Acrylonitrile
ammonia	lb/BP Green Lake	21000			5 Kg/kg Acrylonitrile
Hydrogen Cyanide	lb/BP Green Lake	0			5 Kg/kg Acrylonitrile
Propylene	lb/BP Green Lake	0			5 Kg/kg Acrylonitrile
Molybdenum Trioxide	lb/BP Green Lake	19000			5 Kg/kg Acrylonitrile
acetamide	lb/BP Green Lake	98			Kg/kg Acrylonitrile
acetaldehyde	lb/BP Green Lake	15			Kg/kg Acrylonitrile
Acrylamide	lb/BP Green Lake	350			Kg/kg Acrylonitrile
Pyridine	lb/BP Green Lake	11			Kg/kg Acrylonitrile
To recycle					

Acetonitrile

Heavy metals (Cadmium, Nickel, Cr/b/BP Green Lake 0 5 Kg/kg Acrylonitrile

Deep well injection

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units
Acetonitrile	lb/BP Green Lake	3,800,000.00			Kg/kg Acrylonitrile
Acrolein	lb/BP Green Lake	46			Kg/kg Acrylonitrile
Acrylic acid	lb/BP Green Lake	160000			Kg/kg Acrylonitrile
Acrylonitrile	lb/BP Green Lake	620000			Kg/kg Acrylonitrile
ammonia	lb/BP Green Lake	14000000			Kg/kg Acrylonitrile
Hydrogen Cyanide	lb/BP Green Lake	0			Kg/kg Acrylonitrile
Propylene	lb/BP Green Lake	0			Kg/kg Acrylonitrile
Molybdenum Trioxide	lb/BP Green Lake	55000			Kg/kg Acrylonitrile
acetamide	lb/BP Green Lake	89000			Kg/kg Acrylonitrile
acetaldehyde	lb/BP Green Lake	5900			Kg/kg Acrylonitrile
Acrylamide	lb/BP Green Lake	930000			Kg/kg Acrylonitrile
Pyridine	lb/BP Green Lake	80000			Kg/kg Acrylonitrile

Sheet End

Acetonitrile

336.5812288	17859	0.014394
720 27503.43463	1129082	0.910003
60 3470.930401	69.11	93803.98
		0.075603

hydrin 60

Std. Dev.	DQI
	3
	3
	3

3

Acetonitrile

taken and the proper
o-product allocation

as reported.

and sulfur = 0.5%

kg air per kg
component
1.324134
4.321406
1994.319
77.62792

Acetonitrile

Cyanide compound	Hydroquinone	Formaldehyde	
Acrylic acid	Acrylonitrile	ammonia	
	methanol	Chlorine	Benzene
	Hydrogen Cyanide	Propylene	Molybdenum

Transformed	Transformed
Quan.	Std. Dev.
1.100482758	
0	
0	
0	
0	
0	
5.78119E-07	

MJ/kg Acrylonitrile

0.794673909

0.288925823

0.016883025

1.100482758

10.71550884 Kg water

Electric Demand

Sp Gr	Sp visc	number of pumping stages	Electric Demand
0.806		0.7 Absorber, Separator, Colu	5 2.22E-07
0.7857		0.7 condenser and storage	2 1.37E-09
1		2 Absorber, Separator	2 1.44E-07

These are
guesses

Coolers

2.11E-07

Total

5.78E-07 MJ/Kg Acrylonitrile

Transformed
Quan.

Transformed

Std. Dev.

0

0

0

0

0.475

1.175

0

0

(all out into water emission)

Acetonitrile

Transformed Quan.	Transformed Std. Dev.
0	0
0	0
0	0
1.63642E-06	0
0	0
0	0
7.67072E-06	0
1.50005E-07	0
5.11381E-09	0
5.52292E-05	0
1.44891E-05	0
8.21619E-05	0
2.82964E-05	0
0	0
1.7046E-08	0
6.64795E-08	0
3.80127E-07	0
2.591E-07	0
0.000188725	0
0	0

Transformed Quan.	Transformed Std. Dev.
0	0
0	0
0	0
0	0
0	0
0	0

0
0
0
4.94335E-07
0
0
0
0
0
0
0
0

Transformed
Quan.

Transformed
Std. Dev.

0
5.11381E-09
8.52302E-09
3.74655E-05
5.79565E-07
1.36368E-08
2.04552E-07
6.30703E-08
3.57967E-05
0
0
3.23875E-05
1.67051E-07
2.55691E-08
5.96611E-07
1.87506E-08

Acetonitrile

0

Transformed Quan.	Transformed Std. Dev.
0.006477494	
7.84118E-08	
0.000272737	
0.001056854	
0.023864452	
0	
0	
9.37532E-05	
0.00015171	
1.00572E-05	
0.001585281	
0.000136368	
=====	=====

TABLE 1. INVENTORY FOR BASELINE PBXN-109 DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

	HE Washout			Process	
	1	2	3	4	5
PBXN-109	(525.00)	0.00	509.25	0.00	15.75
TNAZ/Al	0.00	0.00	0.00	0.00	0.00
Asphalt	(18.50)	0.00	0.00	0.00	18.50
Bomb Case	(1,390.00)	0.00	0.00	0.00	1,390.00
Potting	(3.00)	0.00	0.00	0.00	3.00
Felt Pad	?	0.00	0.00	0.00	0.00
Thermal Insulation	(25.00)	0.00	0.00	0.00	25.00
TCA (solvent)	0.00	0.00	0.00	0.00	0.00
Water	0.00	(63,050.40)	0.00	63,050.40	0.00
Steam	0.00	0.00	0.00	0.00	0.00
Fuel	0.00	0.00	0.00	0.00	0.00
Air	0.00	0.00	0.00	0.00	0.00
Electricity, kwh/bomb	0.00	(1,738.00)	0.00	0.00	0.00
Activated Carbon	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	0.00	0.00	0.00
N2	0.00	0.00	0.00	0.00	0.00
H2O	0.00	0.00	0.00	0.00	0.00
H2	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00
H	0.00	0.00	0.00	0.00	0.00
HO	0.00	0.00	0.00	0.00	0.00
NO	0.00	0.00	0.00	0.00	0.00
Al	0.00	0.00	0.00	0.00	0.00
O	0.00	0.00	0.00	0.00	0.00
CH4	0.00	0.00	0.00	0.00	0.00
NH3	0.00	0.00	0.00	0.00	0.00
C2H4	0.00	0.00	0.00	0.00	0.00
C3H6	0.00	0.00	0.00	0.00	0.00
C2H6	0.00	0.00	0.00	0.00	0.00
					-1738

C2H2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C3H8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
CHN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Flue Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Al2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Ash	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
PBXN-109	3	6	7	8	9	Process			
TNAZ/Al	(0.00)	0.00	0.00	0.00	0.00	Total			
Asphalt	0.00	0.00	0.00	0.00	0.00				
Bomb Case	0.00	0.00	0.00	0.00	0.00				
Potting	0.00	0.00	0.00	0.00	0.00				
Felt Pad	0.00	0.00	0.00	0.00	0.00				
Thermal Insulation	0.00	0.00	0.00	0.00	0.00				
TCA (solvent)	0.00	0.00	0.00	0.00	0.00				
Water	0.00	0.00	0.00	0.00	0.00				
Steam	0.00	0.00	0.00	0.00	0.00				
Fuel	0.00 ?	0.00	0.00	0.00	0.00				
Air	0.00	0.00 ?	0.00	0.00	0.00				
Electricity, kwh/bomb	0.00	0.00	0.00	0.00	0.00				
Activated Carbon	0.00	0.00	0.00	0.00	0.00				
CO	0.00	0.00	0.00 ?	0.00	0.00				
N2	0.00	0.00	0.00 ?	0.00	0.00				
H2O	0.00	0.00	0.00 ?	0.00	0.00				
H2	0.00	0.00	0.00 ?	0.00	0.00				
CO2	0.00	0.00	0.00 ?	0.00	0.00				
H	0.00	0.00	0.00 ?	0.00	0.00				
HO	0.00	0.00	0.00 ?	0.00	0.00				
NO	0.00	0.00	0.00 ?	0.00	0.00				
Al	0.00	0.00	0.00 ?	0.00	0.00				

	Wastewater Treatment				Process Total	Solid Wastes	Wastewater Emissions
	4	10	11	12			
O	0.00	0.00	0.00	?	0.00	0	0
CH4	0.00	0.00	0.00		0.00	0	0
NH3	0.00	0.00	0.00		0.00	0	0
C2H4	0.00	0.00	0.00		0.00	0	0
C3H6	0.00	0.00	0.00		0.00	0	0
C2H6	0.00	0.00	0.00		0.00	0	0
C2H2	0.00	0.00	0.00		0.00	0	0
C3H8	0.00	0.00	0.00		0.00	0	0
CHN	0.00	0.00	0.00		0.00	0	0
C	0.00	0.00	0.00		52.38	52.38	52.38
Flue Gas	0.00	0.00	0.00		0.00	0	0
Total gaseous pollutant	0.00	0.00	0.00		0.00	0	0
Al2O3	0.00	0.00	0.00		192.06	192.06	192.06
Ash	0.00	0.00	0.00		244.44	244.44	244.44
PBXN-109	0.00	0.00	0.00		0.00	0	0
TNAZ/Al	0.00	0.00	0.00		0.00	0	0
Asphalt	0.00	0.00	0.00		0.00	0	0
Bomb Case	0.00	0.00	0.00		0.00	0	0
Potting	0.00	0.00	0.00		0.00	0	0
Felt Pad	0.00	0.00	0.00		0.00	0	0
Thermal Insulation	0.00	0.00	0.00		0.00	0	0
TCA (solvent)	0.00	0.00	0.00		0.00	0	0
Water	0.00	0.00	0.75	63,049.65	63050.4	0.752164	63049.648
Steam	0.00	0.00	0.00		0	0	0
Fuel	0.00	0.00	0.00		0	0	0
Air	0.00	0.00	0.00		0	0	0
Electricity, kwh/bomb	0.00	0.00	0.00		0	0	0
Activated Carbon	0.00	(14.29)	14.29	0.00	0	14.291115	0
CO	0.00	0.00	0.00		0	0	0
N2	0.00	0.00	0.00		0	0	0
H2O	0.00	0.00	0.00		0	0	0

H2	0.00	0.00	0.00	0.00	0.00	0	0	0	0
CO2	0.00	0.00	0.00	0.00	0.00	0	0	0	0
H	0.00	0.00	0.00	0.00	0.00	0	0	0	0
HO	0.00	0.00	0.00	0.00	0.00	0	0	0	0
NO	0.00	0.00	0.00	0.00	0.00	0	0	0	0
Al	0.00	0.00	0.00	0.00	0.00	0	0	0	0
O	0.00	0.00	0.00	0.00	0.00	0	0	0	0
CH4	0.00	0.00	0.00	0.00	0.00	0	0	0	0
NH3	0.00	0.00	0.00	0.00	0.00	0	0	0	0
C2H4	0.00	0.00	0.00	0.00	0.00	0	0	0	0
C3H6	0.00	0.00	0.00	0.00	0.00	0	0	0	0
C2H6	0.00	0.00	0.00	0.00	0.00	0	0	0	0
C2H2	0.00	0.00	0.00	0.00	0.00	0	0	0	0
C3H8	0.00	0.00	0.00	0.00	0.00	0	0	0	0
CHN	0.00	0.00	0.00	0.00	0.00	0	0	0	0
C	0.00	0.00	0.00	0.00	0.00	0	0	0	0
Flue Gas	0.00	0.00	0.00	0.00	0.00	0	0	0	0
Total gaseous pollutant	0.00	0.00	0.00	0.00	0.00	0	0	0	0
Al2O3	0.00	0.00	0.00	0.00	0.00	0	0	0	0
Ash	0.00	0.00	0.00	0.00	0.00	0	0	0	0

Solvent Soak

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Process

Total

PBXN-109	(15.75)	0.00	15.75	0.00	0
TNAZ/Al	0.00	0.00	0.00	0.00	0
Asphalt	(18.50)	0.00	18.50	0.00	0
Bomb Case	(1,390.00)	0.00	0.00	1,390.00	0
Potting	(3.00)	0.00	0.00	3.00	0
Felt Pad	0.00	0.00	0.00	0.00	0
Thermal Insulation	(25.00)	0.00	0.00	25.00	0
TCA (solvent)	0.00	(212.50)	212.50	0.00	0
Water	0.00	0.00	0.00	0.00	0
Steam	0.00	0.00	0.00	0.00	0
Fuel	0.00	0.00	0.00	0.00	0

	Air	Electricity, kwh/bomb	Activated Carbon	CO	N2	H2O	H2	CO2	H	HO	NO	Al	O	CH4	NH3	C2H4	C3H6	C2H6	C2H2	C3H8	CHN	C	Flue Gas	Total gaseous pollutant	Al2O3	Ash																
														Incinerator																												
														14	16	17	18	19	Process		Air		Solid																			
																			Total		Emissions	Wastes																				
PBXN-109	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-15.75	0	0	0												
TNAZ/Al	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0												
Asphalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-18.5	0	0	0												
Bomb Case	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0												
Potting	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0												

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Flue Gas	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Total gaseous pollutant	0	0.00	0.00 ?	0.00	0.00	0.00	0	0	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Ash	0	0.00	0.00	0.00 ?	0.00	0.00	0 ?	0	0

TABLE 2. INVENTORY FOR OPTION 1 PBXN-109 DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

	HE Removal				
	1	2	3	4	5
PBXN-109	(525.00)	0.00	509.25	0.00	15.75
TNAZ/Al	0.00	0.00	0.00	0.00	0.00
Asphalt	(18.50)	0.00	0.00	0.00	18.50
Bomb Case	(1,390.00)	0.00	0.00	0.00	1,390.00
Potting	(3.00)	0.00	0.00	0.00	3.00
Felt Pad	?	0.00	0.00	0.00	0.00
Thermal Insulation	(25.00)	0.00	0.00	0.00	25.00
TCA (solvent)	0.00	0.00	0.00	0.00	0.00
Water	0.00	(63,050.40)	0.00	63,050.40	0.00
Steam	0.00	0.00	0.00	0.00	0.00
Fuel	0.00	0.00	0.00	0.00	0.00
Air	0.00	0.00	0.00	0.00	0.00
Electricity, kwh/bomb	0.00	(1,738.00)	0.00	0.00	0.00
Activated Carbon	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	0.00	0.00	0.00
N ₂	0.00	0.00	0.00	0.00	0.00
H ₂ O, vapor	0.00	0.00	0.00	0.00	0.00
H ₂	0.00	0.00	0.00	0.00	0.00
CO ₂	0.00	0.00	0.00	0.00	0.00
H	0.00	0.00	0.00	0.00	0.00
HO	0.00	0.00	0.00	0.00	0.00
NO	0.00	0.00	0.00	0.00	0.00
Al	0.00	0.00	0.00	0.00	0.00
O	0.00	0.00	0.00	0.00	0.00
CH ₄	0.00	0.00	0.00	0.00	0.00
NH ₃	0.00	0.00	0.00	0.00	0.00
C ₂ H ₄	0.00	0.00	0.00	0.00	0.00
C ₃ H ₆	0.00	0.00	0.00	0.00	0.00
C ₂ H ₆	0.00	0.00	0.00	0.00	0.00
C ₂ H ₂	0.00	0.00	0.00	0.00	0.00
C ₃ H ₈	0.00	0.00	0.00	0.00	0.00
CHN	0.00	0.00	0.00	0.00	0.00
C	0.00	0.00	0.00	0.00	0.00

Demil. Option 1

	3	6	7	8	9	Solid Waste	Air Emissions	Resource Consumption
Flue Gas	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Total gaseous pollutant	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Al2O3	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Ash	0.00	0.00	0.00	0.00	0.00	0.00	0	0
PBXN-109	-509.25	0.00	0.00	0.00	0.00	0.00	0	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0.00	0	0
Asphalt	0	0.00	0.00	0.00	0.00	0.00	0	0
Bomb Case	0	0.00	0.00	0.00	0.00	0.00	0	0
Potting	0	0.00	0.00	0.00	0.00	0.00	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0	0
Water	0	0.00	0.00	0.00	0.00	0.00	0	0
Steam	0	0.00	0.00	0.00	0.00	0.00	0	0
Fuel	0 ?	0.00	0.00	0.00	0.00	0.00	0	0
Air	0	0.00 ?	0.00	0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0.00	0	0
CO	0	0.00	0.00 ?	0.00 ?	0.00	0.00	?	0
N2	0	0.00	0.00 ?	0.00 ?	0.00	0.00	?	0
H2O, vapor	0	0.00	0.00 ?	0.00 ?	0.00	0.00	?	0
H2	0	0.00	0.00 ?	0.00 ?	0.00	0.00	?	0
CO2	0	0.00	0.00 ?	0.00 ?	0.00	0.00	?	0
H	0	0.00	0.00 ?	0.00 ?	0.00	0.00	?	0
HO	0	0.00	0.00 ?	0.00 ?	0.00	0.00	?	0
NO	0	0.00	0.00 ?	0.00 ?	0.00	0.00	?	0
Al	0	0.00	0.00 ?	0.00 ?	0.00	0.00	?	0
O	0	0.00	0.00 ?	0.00 ?	0.00	0.00	?	0
CH4	0	0.00	0.00	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0.00	0.00	0	0

Demil. Option 1

C3H8	0	0.00	0.00	0.00	0.00	0.00	0
CHN	0	0.00	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	52.38	0	0
Flue Gas	0	0.00	0.00	0.00	0	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0	0	0
Al2O3	0	0.00	0.00	0.00	192.06	0	0
Ash	0	0.00	0.00	0.00	244.44	0	0

	4	10	11	12	16	22	Solid Waste	Wastewater Emissions
PBXN-109	0	0.00	0.00	0.00	0	0	0	0
TNAZ/Al	0	0.00	0.00	0.00	0	0	0	0
Asphalt	0	0.00	0.00	0.00	0	0	0	0
Bomb Case	0	0.00	0.00	0.00	0	0	0	0
Potting	0	0.00	0.00	0.00	0	0	0	0
Felt Pad	0	0.00	0.00	0.00	0	0	0	0
Thermal Insulation	0	0.00	0.00	0.00	0	0	0	0
TCA (solvent)	0	0.00	0.00	0.00	0	0	0	0
Water	-63050.4	0.00	0.77	64,390.94	-1296	-45.3048	0.7681651	64390.937
Steam	0	0.00	0.00	0.00	0	0	0	0
Fuel	0	0.00	0.00	0.00	0	0	0	0
Air	0	0.00	0.00	0.00	0	0	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0	0	0	0
Activated Carbon	0	(14.60)	14.60	0.00	0	0	14.595138	0
CO	0	0.00	0.00	0.00	0	0	0	0
N2	0	0.00	0.00	0.00	0	0	0	0
H2O, vapor	0	0.00	0.00	0.00	0	0	0	0
H2	0	0.00	0.00	0.00	0	0	0	0
CO2	0	0.00	0.00	0.00	0	0	0	0
H	0	0.00	0.00	0.00	0	0	0	0
HO	0	0.00	0.00	0.00	0	0	0	0
NO	0	0.00	0.00	0.00	0	0	0	0
Al	0		0.00	0.00	0	0	0	0
O	0	0.00	0.00	0.00	0	0	0	0
CH4	0	0.00	0.00	0.00	0	0	0	0
NH3	0	0.00	0.00	0.00	0	0	0	0
C2H4	0	0.00	0.00	0.00	0	0	0	0

Demil. Option 1

	5	13	14	15	16	17	18	19	Wastewater Emissions
C3H6	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C2H6	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C2H2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C3H8	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
CHN	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Flue Gas	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Ash	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
PBXN-109	-15.75	0.00	0.00	0.00	0.00	0.00	15.75	0.00	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Asphalt	-18.5	0.00	0.00	0.00	0.00	0.00	18.32	0.18	0
Bomb Case	-1390	0.00	0.00	0.00	0.00	0.00	0.00	1,390.00	0
Potting	-3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Thermal Insulation	-25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Water	0	0.00	(1,296.00)	0.00	0.00	714.00	0.00	0.00	714
Steam	0	(714.00)	0.00	0.00	1,296.00	0.00	0.00	0.00	0
Fuel	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Air	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
CO	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
N2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
H2O, vapor	0	0.00	0.00	238.00	0.00	0.00	0.00	0.00	0
H2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
CO2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
H	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
HO	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
NO	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Al	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
O	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

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Demil. Option 1

	21	23	24	25	26	Air Emissions	Solid Waste
NO	0	0.00	0.00	0.00	0.00	0.00	0
Al	0	0.00	0.00	0.00	0.00	0.00	0
O	0	0.00	0.00	0.00	0.00	0.00	0
CH4	0	0.00	0.00	0.00	0.00	0.00	0
NH3	0	0.00	0.00	0.00	0.00	0.00	0
C2H4	0	0.00	0.00	0.00	0.00	0.00	0
C3H6	0	0.00	0.00	0.00	0.00	0.00	0
C2H6	0	0.00	0.00	0.00	0.00	0.00	0
C2H2	0	0.00	0.00	0.00	0.00	0.00	0
C3H8	0	0.00	0.00	0.00	0.00	0.00	0
CHN	0	0.00	0.00	0.00	0.00	0.00	0
C	0	0.00	0.00	0.00	0.00	0.00	0
Flue Gas	0	0.00	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0.00	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0
Ash	0	0.00	0.00	0.00	0.00	0.00	0
PBXN-109	-15.75	0.00	0.00	0.00	0.00	0.00	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0.00	0
Asphalt	-18.315	0.00	0.00	0.00	0.00	0.00	0
Bomb Case	0	0.00	0.00	0.00	0.00	0.00	0
Potting	0	0.00	0.00	0.00	0.00	0.00	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0.00	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0
Water	-0.695204082	0.00	0.00	0.00	0.00	0.00	0
Steam	0	0.00	0.00	0.00	0.00	0.00	0
Fuel	0 ?	0.00	0.00	0.00	0.00	0.00	0
Air	0	0.00 ?	0.00	0.00	0.00	0.00	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0.00	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0.00	0
CO	0	0.00	0.00 ?	0.00	0.00 ?	0.00 ?	0
N2	0	0.00	0.00 ?	0.00	0.00 ?	0.00 ?	0
H2O, vapor	0	0.00	0.00 ?	0.00	0.00 ?	0.00 ?	0
H2	0	0.00	0.00	0.00	0.00	0.00	0

CO2	0	0.00	0.00 ?	0.00 ?	0
H	0	0.00	0.00	0.00	0
HO	0	0.00	0.00	0.00	0
NO	0	0.00	0.00	0.00	0
Al	0	0.00	0.00	0.00	0
O	0	0.00	0.00	0.00	0
CH4	0	0.00	0.00	0.00	0
NH3	0	0.00	0.00	0.00	0
C2H4	0	0.00	0.00	0.00	0
C3H6	0	0.00	0.00	0.00	0
C2H6	0	0.00	0.00	0.00	0
C2H2	0	0.00	0.00	0.00	0
C3H8	0	0.00	0.00	0.00	0
CHN	0	0.00	0.00	0.00	0
C	0	0.00	0.00	0.00	0
Flue Gas	0	0.00	0.00 ?	0.00 ?	0
Total gaseous pollutant	0	0.00	0.00	0.00	0
Al2O3	0	0.00	0.00	0.00	0
Ash	0 ?	0.00	0.00	0.00	0

PBXN-109	19	27	28	29	30	31	Solid Waste	Recycle
TNAZ/Al	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Asphalt	-0.185	0.00	0.00	0.00	0.00	0.00	0.00	0
Bomb Case	-1390	0.00	0.00	0.00	0.00	1,390.00	0.00	1390
Potting	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0.00	0.00	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Water	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Steam	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Fuel	0 ?	0.00	0.00	0.00	0.00	0.00	0.00	0
Air	0	0.00 ?	0.00	0.00	0.00	0.00	0.00	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0.00	0.00	0
CO	0	0.00	0.00 ?	0.00	0.00	0.00	0.00	0

N2
H2O, vapor
H2
CO2
H
HO
NO
Al
O
CH4
NH3
C2H4
C3H6
C2H6
C2H2
C3H8
CHN
C
Flue Gas
Total gaseous pollutant
Al2O3
Ash

	0	0.00	0.00	0.00	?	0.00	0.00	0.00	0.00	0.00	0.00	0
N ₂	0	0.00										0
H ₂ O, vapor	0	0.00	?									0
H ₂	0	0.00				0.00						0
CO ₂	0	0.00	?									0
H	0	0.00				0.00						0
HO	0	0.00				0.00						0
NO	0	0.00				0.00						0
Al	0	0.00				0.00						0
O	0	0.00				0.00						0
CH ₄	0	0.00				0.00						0
NH ₃	0	0.00				0.00						0
C ₂ H ₄	0	0.00				0.00						0
C ₃ H ₆	0	0.00				0.00						0
C ₂ H ₆	0	0.00				0.00						0
C ₂ H ₂	0	0.00				0.00						0
C ₃ H ₈	0	0.00				0.00						0
CHN	0	0.00				0.00						0
C	0	0.00				0.00						0
Flue Gas	0	0.00	?									0
Total gaseous pollutant	0	0.00				0.00						0
Al ₂ O ₃	0	0.00				0.00						0
Ash	0	0.00				0.00	?					0
						0.00						0

TABLE 3. INVENTORY FOR OPTION 2 TNAZ DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

	HE Removal				
	1	2	3	4	5
PBXN-109	0.00	0.00	0.00	0.00	0.00
TNAZ/Al	(525.00)	0.00	509.25	0.00	15.75
Asphalt	(18.50)	0.00	0.00	0.00	18.50
Bomb Case	(1,390.00)	0.00	0.00	0.00	1,390.00
Potting	(3.00)	0.00	0.00	0.00	3.00
Felt Pad	?	0.00	0.00	0.00	?
Thermal Insulation	(25.00)	0.00	0.00	0.00	25.00
TCA (solvent)	0.00	0.00	0.00	0.00	0.00
Water	0.00	(63,050.40)	0.00	63,050.40	0.00
Steam	0.00	0.00	0.00	0.00	0.00
Fuel	0.00	0.00	0.00	0.00	0.00
Air	0.00	0.00	0.00	0.00	0.00
Electricity, kwh/bomb	0.00	(1,738.00)	0.00	0.00	0.00
Activated Carbon	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	0.00	0.00	0.00
N ₂	0.00	0.00	0.00	0.00	0.00
H ₂ O	0.00	0.00	0.00	0.00	0.00
H ₂	0.00	0.00	0.00	0.00	0.00
CO ₂	0.00	0.00	0.00	0.00	0.00
H	0.00	0.00	0.00	0.00	0.00
HO	0.00	0.00	0.00	0.00	0.00
NO	0.00	0.00	0.00	0.00	0.00
Al	0.00	0.00	0.00	0.00	0.00
O	0.00	0.00	0.00	0.00	0.00
CH ₄	0.00	0.00	0.00	0.00	0.00
NH ₃	0.00	0.00	0.00	0.00	0.00
C ₂ H ₄	0.00	0.00	0.00	0.00	0.00
C ₃ H ₆	0.00	0.00	0.00	0.00	0.00
C ₂ H ₆	0.00	0.00	0.00	0.00	0.00
C ₂ H ₂	0.00	0.00	0.00	0.00	0.00
C ₃ H ₈	0.00	0.00	0.00	0.00	0.00
CHN	0.00	0.00	0.00	0.00	0.00
C	0.00	0.00	0.00	0.00	0.00

	3	6	7	8	9	Air Emissions	Solid Waste	
Flue Gas	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Total gaseous pollutant	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Al2O3	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Ash	0.00	0.00	0.00	0.00	0.00	0.00	0	0
PBXN-109	0	0.00	0.00	0.00	0.00	0	0	0
TNAZ/Al	-509.25	0.00	0.00	0.00	0.00	0	0	0
Asphalt	0	0.00	0.00	0.00	0.00	0	0	0
Bomb Case	0	0.00	0.00	0.00	0.00	0	0	0
Potting	0	0.00	0.00	0.00	0.00	0	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0	0	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0	0	0
Water	0	0.00	0.00	0.00	0.00	0	0	0
Steam	0	0.00	0.00	0.00	0.00	0	0	0
Fuel	0 ?	0.00	0.00	0.00	0.00	0	0	0
Air	0	0.00 ?	0.00	0.00	0.00	0	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0	0
CO	0	0.00	0.00	(174.16)	0.00	-174.1635	0	0
N2	0	0.00	0.00	(118.81)	0.00	-118.8056	0	0
H2O	0	0.00	0.00	(9.62)	0.00	-9.6224	0	0
H2	0	0.00	0.00	(6.93)	0.00	-6.9258	0	0
CO2	0	0.00	0.00	(6.31)	0.00	-6.3147	0	0
H	0	0.00	0.00	(0.50)	0.00	-0.5044	0	0
HO	0	0.00	0.00	(0.35)	0.00	-0.3492	0	0
NO	0	0.00	0.00	(0.05)	0.00	-0.0485	0	0
Al	0	0.00	0.00	(0.05)	0.00	-0.0485	0	0
O	0	0.00	0.00	(0.05)	0.00	-0.0485	0	0
CH4	0	0.00	0.00	0.00	0.00	0	0	0
NH3	0	0.00	0.00	0.00	0.00	0	0	0
C2H4	0	0.00	0.00	0.00	0.00	0	0	0
C3H6	0	0.00	0.00	0.00	0.00	0	0	0
C2H6	0	0.00	0.00	0.00	0.00	0	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	0	0
C3H8	0	0.00	0.00	0.00	0.00	0	0	0

	4	10	11	12	16	21	Solid Waste	Wastewater Emissions
CHN	0	0.00	0.00	0.00	0.00	0	0	0
C	0	0.00	0.00	0.00	52.38	0	52.38	0
Flue Gas	0	0.00	0.00	0.00	0.00	0	0	0
Total gaseous pollutant	0	0.00	0.00	(175.11)	0.00	-175.1141	0	0
Al2O3	0	0.00	0.00	0.00	(192.29)	0	-192.2928	0
Ash	0	0.00	0.00	0.00	(139.91)	0	-139.9128	0
PBXN-109	0	0.00	0.00	0.00	0	0	0	0
TNAZ/Al	0	0.00	0.00	0.00	0	0	0	0
Asphalt	0	0.00	0.00	0.00	0	0	0	0
Bomb Case	0	0.00	0.00	0.00	0	0	0	0
Potting	0	0.00	0.00	0.00	0	0	0	0
Felt Pad	0	0.00	0.00	0.00	0	0	0	0
Thermal Insulation	0	0.00	0.00	0.00	0	0	0	0
TCA (solvent)	0	0.00	0.00	0.00	0	0	0	0
Water	-63050.4	0.00	0.74	61,706.97	1296	0	0.7361462	61706.969
Steam	0	0.00	0.00	0.00	0	0	0	0
Fuel	0	0.00	0.00	0.00	0	0	0	0
Air	0	0.00	0.00	0.00	0	0	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0	0	0	0
Activated Carbon	0	13.99	13.99	0.00	0	13.986778	13.986778	0
CO	0	0.00	0.00	0.00	0	0	0	0
N2	0	0.00	0.00	0.00	0	0	0	0
H2O	0	0.00	0.00	0.00	0	0	0	0
H2	0	0.00	0.00	0.00	0	0	0	0
CO2	0	0.00	0.00	0.00	0	0	0	0
H	0	0.00	0.00	0.00	0	0	0	0
HO	0	0.00	0.00	0.00	0	0	0	0
NO	0	0.00	0.00	0.00	0	0	0	0
Al	0	0.00	0.00	0.00	0	0	0	0
O	0	0.00	0.00	0.00	0	0	0	0
CH4	0	0.00	0.00	0.00	0	0	0	0
NH3	0	0.00	0.00	0.00	0	0	0	0
C2H4	0	0.00	0.00	0.00	0	0	0	0
C3H6	0	0.00	0.00	0.00	0	0	0	0

Demil. Option 2

	5	13	14	15	16	17	18	19	Air Emissions	Wastewater Emissions
C2H6	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	15.75	0.00	0	0
C3H8	0	0.00	0.00	0.00	0.00	0	18.32	0.18	0	0
CHN	0	0.00	0.00	0.00	0.00	0	0.00	1,390.00	0	0
C	0	0.00	0.00	0.00	0.00	0	0.00	3.00	0	0
Flue Gas	0	0.00	0.00	0.00	0.00	0	0.00	?	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0	0.00	25.00	0	0
Al2O3	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Ash	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
PBXN-109	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
TNAZ/Al	-15.75	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Asphalt	-18.5	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Bomb Case	-1390	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Potting	-3	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0	0.00	?	0	0
Thermal Insulation	-25	0.00	0.00	0.00	0.00	0	0.00	25.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Water	0	0.00	(1,296.00)	0.00	(1,296.00)	-714	0.00	0.00	0	-714
Steam	0	(714.00)	0.00	0.00	0.00	0	0.00	0.00	0	0
Fuel	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Air	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Electricity, kw/h/bomb	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
CO	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
N2	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
H2O	0	0.00	0.00	238.00	0.00	0	0.00	0.00	238	0
H2	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
CO2	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
H	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
HO	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
NO	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Al	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
O	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0

CH4	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
NH3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
C2H4	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
C3H6	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
C2H6	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
C2H2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
C3H8	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
CHN	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
C	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
Flue Gas	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0
Ash	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0	0

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Demil. Option 2

	21	23	24	25	27	Solid Waste	Air Emissions
PBXN-109	0	0.00	0.00	0.00	0.00	0.00	0
TNAZ/Al	-15.75	0.00	0.00	0.00	0.00	0.00	0
Asphalt	-18.315	0.00	0.00	0.00	0.00	0.00	0
Bomb Case	0	0.00	0.00	0.00	0.00	0.00	0
Potting	0	0.00	0.00	0.00	0.00	0.00	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0.00	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0
Water	-0.695204082	0.00	0.00	0.00	0.00	0.00	0
Steam	0	0.00	0.00	0.00	0.00	0.00	0
Fuel	0 ?	0.00	0.00	0.00 ?	0.00	0 ?	0
Air	0	0.00 ?	0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0
H	0	0.00	0.00	0.00	0.00		
HO	0	0.00	0.00	0.00	0.00		
NO	0	0.00	0.00	0.00	0.00		
Al	0	0.00	0.00	0.00	0.00		
O	0	0.00	0.00	0.00	0.00		
CH4	0	0.00	0.00	0.00	0.00		
NH3	0	0.00	0.00	0.00	0.00		
C2H4	0	0.00	0.00	0.00	0.00		
C3H6	0	0.00	0.00	0.00	0.00		
C2H6	0	0.00	0.00	0.00	0.00		
C2H2	0	0.00	0.00	0.00	0.00		
C3H8	0	0.00	0.00	0.00	0.00		
CHN	0	0.00	0.00	0.00	0.00		
C	0	0.00	0.00	0.00	0.00		
Flue Gas	0	0.00	0.00	0.00	0.00		
Total gaseous pollutant	0	0.00	0.00	0.00	0.00		
Al2O3	0	0.00	0.00	0.00	0.00		
Ash	0	0.00	0.00	0.00	0.00		

Demil. Option 2

CO	0	0.00	0.00	0.00	0.00	0.00	0
N2	0	0.00	0.00	0.00	0.00	0.00	0
H2O	0	0.00	0.00	0.00	0.00	0.00	0
H2	0	0.00	0.00	0.00	0.00	0.00	0
CO2	0	0.00	0.00	0.00	0.00	0.00	0
H	0	0.00	0.00	0.00	0.00	0.00	0
HO	0	0.00	0.00	0.00	0.00	0.00	0
NO	0	0.00	0.00	0.00	0.00	0.00	0
Al	0	0.00	0.00	0.00	0.00	0.00	0
O	0	0.00	0.00	0.00	0.00	0.00	0
CH4	0	0.00	0.00	0.00	0.00	0.00	0
NH3	0	0.00	0.00	0.00	0.00	0.00	0
C2H4	0	0.00	0.00	0.00	0.00	0.00	0
C3H6	0	0.00	0.00	0.00	0.00	0.00	0
C2H6	0	0.00	0.00	0.00	0.00	0.00	0
C2H2	0	0.00	0.00	0.00	0.00	0.00	0
C3H8	0	0.00	0.00	0.00	0.00	0.00	0
CHN	0	0.00	0.00	0.00	0.00	0.00	0
C	0	0.00	0.00	0.00	0.00	0.00	0
Flue Gas	0	0.00	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0.00	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0
Ash	0	0.00	0.00	0.00	0.00	0.00	0

PBXN-109	19	26	28	29	30	31	Air Emissions	Solid Waste	Recycle
TNAZ/Al	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Asphalt	-0.185	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Bomb Case	-1390	0.00	0.00	0.00	0.00	1,390.00	0	0	0
Potting	-3	0.00	0.00	0.00	0.00	0.00	0	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Thermal Insulation	-25	0.00	0.00	0.00	0.00	0.00	0	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Water	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Steam	0	0.00	0.00	0.00	0.00	0.00	0	0	0

[illegible]

TABLE 4. INVENTORY FOR OPTION 3 TNAZ DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

	1	2	3	4	4A	5	6	7	Air Emissions	wastewater Emissions
PBXN-109	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
TNAZ/Al	(525.00)	0.00	0.00	525.00	0.00	0.00	0.00	0.00	0	0
Asphalt	(18.50)	0.00	0.00	18.32	0.00	0.00	0.00	0.18	0	0
Bomb Case	(1,390.00)	0.00	0.00	0.00	0.00	0.00	0.00	1,390.00	0	0
Potting	(3.00)	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0	0
Felt Pad		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Thermal Insulation	(25.00)	0.00	0.00	0.00	0.00	0.00	0.00	25.00	0	0
TCA (solvent)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Water	0.00	0.00	(1,296.00)	0.00	0.00	1,296.00	0.00	0.00	0	0
Steam	0.00	(981.00)	0.00	0.00	327.00	0.00	654.00	0.00	327	654
Fuel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Air	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Activated Carbon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
CO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
N2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
H2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
H2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
HO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
NO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Al	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
CH4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
NH3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C2H4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C3H6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C2H6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C2H2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C3H8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
CHN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0

Flue Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Al2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Ash	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

	Solidification									
	4	8	9	10						
PBXN-109	0	0.00	0.00	0.00						
TNAZ/Al	-525	0.00	525.00	0.00						
Asphalt	-18.315	0.00	18.32	0.00						
Bomb Case	0	0.00	0.00	0.00						
Potting	0	0.00	0.00	0.00						
Felt Pad	0	0.00	0.00	0.00						
Thermal Insulation	0	0.00	0.00	0.00						
TCA (solvent)	0	0.00	0.00	0.00						
Water	0	(2,284.00)	11.09	(2,295.09)						
Steam	0	0.00	0.00	0.00						
Fuel	0	0.00	0.00	0.00						
Air	0	0.00	0.00	0.00						
Electricity, kwh/bomb	0	0.00	0.00	0.00						
Activated Carbon	0	0.00	0.00	0.00						
CO	0	0.00	0.00	0.00						
N2	0	0.00	0.00	0.00						
H2O	0	0.00	0.00	0.00						
H2	0	0.00	0.00	0.00						
CO2	0	0.00	0.00	0.00						
H	0	0.00	0.00	0.00						
HO	0	0.00	0.00	0.00						
NO	0	0.00	0.00	0.00						
Al	0	0.00	0.00	0.00						
O	0	0.00	0.00	0.00						
CH4	0	0.00	0.00	0.00						
NH3	0	0.00	0.00	0.00						
C2H4	0	0.00	0.00	0.00						
C3H6	0	0.00	0.00	0.00						
C2H6	0	0.00	0.00	0.00						

	5	10	11	12	13	Solid Waste	Wastewater Emissions
C2H2	0	0.00	0.00	0.00	0.00	0.00	0
C3H8	0	0.00	0.00	0.00	0.00	0.00	0
CHN	0	0.00	0.00	0.00	0.00	0.00	0
C	0	0.00	0.00	0.00	0.00	0.00	0
Flue Gas	0	0.00	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0.00	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0
Ash	0	0.00	0.00	0.00	0.00	0.00	0
PBXN-109	0	0	0.00	0.00	0.00	0.00	0
TNAZ/Al	0	0	0.00	0.00	0.00	0.00	0
Asphalt	0	0	0.00	0.00	0.00	0.00	0
Bomb Case	0	0	0.00	0.00	0.00	0.00	0
Potting	0	0	0.00	0.00	0.00	0.00	0
Felt Pad	0	0	0.00	0.00	0.00	0.00	0
Thermal Insulation	0	0	0.00	0.00	0.00	0.00	0
TCA (solvent)	0	0	0.00	0.00	0.00	0.00	0
Water	-1296	2295.08806	0.00	(0.03)	(999.06)	-0.027379407	-999.06068
Steam	0	0	0.00	0.00	0.00	0.00	0
Fuel	0	0	0.00	0.00	0.00	0.00	0
Air	0	0	0.00	0.00	0.00	0.00	0
Electricity, kwh/bomb	0	0	0.00	0.00	0.00	0.00	0
Activated Carbon	0	0	(0.52)	(0.52)	0.00	-0.520208724	0
CO	0	0	0.00	0.00	0.00	0.00	0
N2	0	0	0.00	0.00	0.00	0.00	0
H2O	0	0	0.00	0.00	0.00	0.00	0
H2	0	0	0.00	0.00	0.00	0.00	0
CO2	0	0	0.00	0.00	0.00	0.00	0
H	0	0	0.00	0.00	0.00	0.00	0
HO	0	0	0.00	0.00	0.00	0.00	0
NO	0	0	0.00	0.00	0.00	0.00	0
Al	0	0	0.00	0.00	0.00	0.00	0
O	0	0	0.00	0.00	0.00	0.00	0
CH4	0	0	0.00	0.00	0.00	0.00	0

Demil. Option 3

	7	14	15	16	17	18	Air Emissions	Solid Wastes	Recycle
NH3	0	0	0.00	0.00	0.00	0.00	0	0	0
C2H4	0	0	0.00	0.00	0.00	0.00	0	0	0
C3H6	0	0	0.00	0.00	0.00	0.00	0	0	0
C2H6	0	0	0.00	0.00	0.00	0.00	0	0	0
C2H2	0	0	0.00	0.00	0.00	0.00	0	0	0
C3H8	0	0	0.00	0.00	0.00	0.00	0	0	0
CHN	0	0	0.00	0.00	0.00	0.00	0	0	0
C	0	0	0.00	0.00	0.00	0.00	0	0	0
Flue Gas	0	0	0.00	0.00	0.00	0.00	0	0	0
Total gaseous pollutant	0	0	0.00	0.00	0.00	0.00	0	0	0
Al2O3	0	0	0.00	0.00	0.00	0.00	0	0	0
Ash	0	0	0.00	0.00	0.00	0.00	0	0	0
PBXN-109	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Asphalt	-0.185	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Bomb Case	-1390	0.00	0.00	0.00	0.00	0.00	1,390.00	0	1390
Potting	-3	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Thermal Insulation	-25	0.00	0.00	0.00	0.00	0.00	0.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Water	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Steam	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Fuel	0 ?	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Air	0	0.00 ?	0.00	0.00	0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
CO	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
N2	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
H2O	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
H2	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
CO2	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
H	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0
HO	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0

Demil. Option 3

NO	0	0.00	0.00	0.00	0.00	0.00	0
Al	0	0.00	0.00	0.00	0.00	0.00	0
O	0	0.00	0.00	0.00	0.00	0.00	0
CH4	0	0.00	0.00	0.00	0.00	0.00	0
NH3	0	0.00	0.00	0.00	0.00	0.00	0
C2H4	0	0.00	0.00	0.00	0.00	0.00	0
C3H6	0	0.00	0.00	0.00	0.00	0.00	0
C2H6	0	0.00	0.00	0.00	0.00	0.00	0
C2H2	0	0.00	0.00	0.00	0.00	0.00	0
C3H8	0	0.00	0.00	0.00	0.00	0.00	0
CHN	0	0.00	0.00	0.00	0.00	0.00	0
C	0	0.00	0.00	0.00	0.00	0.00	0
Flue Gas	0	0.00	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0.00	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0
Ash	0	0.00	0.00	0.00	0.00	0.00	0

	9	19	20	21	22	Air Emissions	Solid Waste
PBXN-109	0	0.00	0.00	0.00	0.00	0.00	0
TNAZ/Al	-525	0.00	0.00	0.00	0.00	0.00	0
Asphalt	-18,315	0.00	0.00	0.00	0.00	0.00	0
Bomb Case	0	0.00	0.00	0.00	0.00	0.00	0
Potting	0	0.00	0.00	0.00	0.00	0.00	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0.00	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0
Water	-11,088,0612	0.00	0.00	0.00	0.00	0.00	0
Steam	0	0.00	0.00	0.00	0.00	0.00	0
Fuel	0 ?	0.00	0.00	0.00	0.00	0.00	0
Air	0	0.00 ?	0.00	0.00	0.00	0.00	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0.00	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0.00	0
CO	0	0.00	0.00	179.55	0.00	179.55	0
N2	0	0.00	0.00	122.48	0.00	122.48	0

Demil. Option 3

H2O	0	0.00	0.00	9.92	0.00	9.92	0
H2	0	0.00	0.00	7.14	0.00	7.14	0
CO2	0	0.00	0.00	6.51	0.00	6.51	0
H	0	0.00	0.00	0.52	0.00	0.52	0
HO	0	0.00	0.00	0.36	0.00	0.36	0
NO	0	0.00	0.00	0.05	0.00	0.05	0
Al	0	0.00	0.00	0.05	0.00	0.05	0
O	0	0.00	0.00	0.05	0.00	0.05	0
CH4	0	0.00	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00	0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	198.24	198.24	198.24
Ash	0	0.00	0.00	0.00	198.24	198.24	198.24

		HE/Asphalt Melting		Wastewater	
		23	24	25	26
PBXN-109	9	0	0.00	0.00	0.00
TNAZ/Al	0	0.00	0.00	0.19	524.82
Asphalt	-525	0.00	0.00	18.32	0.00
Bomb Case	-18.315	0.00	0.00	0.00	0.00
Potting	0	0.00	0.00	0.00	0.00
Felt Pad	0	0.00	0.00	0.00	0.00
Thermal Insulation	0	0.00	0.00	0.00	0.00
TCA (solvent)	0	0.00	0.00	0.00	0.00
Water	-11.0880612	0.00	162.00	0.00	0.00
Steam	0	(162.00)	0.00	0.00	0.00
Fuel	0	0.00	0.00	0.00	0.00
Air	0	0.00	0.00	0.00	0.00
				162	0
				0	0
				0	0
				0	0

Demil. Option 3

Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0
CO	0	0.00	0.00	0.00	0.00	0
N2	0	0.00	0.00	0.00	0.00	0
H2O	0	0.00	0.00	0.00	0.00	0
H2	0	0.00	0.00	0.00	0.00	0
CO2	0	0.00	0.00	0.00	0.00	0
H	0	0.00	0.00	0.00	0.00	0
HO	0	0.00	0.00	0.00	0.00	0
NO	0	0.00	0.00	0.00	0.00	0
Al	0	0.00	0.00	0.00	0.00	0
O	0	0.00	0.00	0.00	0.00	0
CH4	0	0.00	0.00	0.00	0.00	0
NH3	0	0.00	0.00	0.00	0.00	0
C2H4	0	0.00	0.00	0.00	0.00	0
C3H6	0	0.00	0.00	0.00	0.00	0
C2H6	0	0.00	0.00	0.00	0.00	0
C2H2	0	0.00	0.00	0.00	0.00	0
C3H8	0	0.00	0.00	0.00	0.00	0
CHN	0	0.00	0.00	0.00	0.00	0
C	0	0.00	0.00	0.00	0.00	0
Flue Gas	0	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0
Al2O3	0	0.00	0.00	0.00	0.00	0
Ash	0	0.00	0.00	0.00	0.00	0

	26	27	28	29	Recycle	
PBXN-109	0	0.00	0.00	0.00	0	
TNAZ/Al	-524,815	0.00	0.19	0.00	0.185	
Asphalt	0	0.00	18.32	0.00	18.315	
Bomb Case	0	0.00	0.00	0.00	0	
Potting	0	0.00	0.00	0.00	0	
Felt Pad	0	0.00	0.00	0.00	0	
Thermal Insulation	0	0.00	0.00	0.00	0	
TCA (solvent)	0	0.00	0.00	0.00	0	
Water	0	1,155.00	0.38	1,154.62	0.37755102	

Pollutant	Wastewater Treatment				Solid Waste	Wastewater Emissions
	30			31		
	29	30	31	32		
Steam	0	0.00	0.00	0.00	0	0
Fuel	0	0.00	0.00	0.00	0	0
Air	0	0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0	0
CO	0	0.00	0.00	0.00	0	0
N2	0	0.00	0.00	0.00	0	0
H2O	0	0.00	0.00	0.00	0	0
H2	0	0.00	0.00	0.00	0	0
CO2	0	0.00	0.00	0.00	0	0
H	0	0.00	0.00	0.00	0	0
HO	0	0.00	0.00	0.00	0	0
NO	0	0.00	0.00	0.00	0	0
Al	0	0.00	0.00	0.00	0	0
O	0	0.00	0.00	0.00	0	0
CH4	0	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0	0
Ash	0	0.00	0.00	0.00	0	0
PBXN-109	0	0.00	0.00	0.00	0	0
TNAZ/Al	0	0.00	0.00	0.00	0	0
Asphalt	0	0.00	0.00	0.00	0	0
Bomb Case	0	0.00	0.00	0.00	0	0
Potting	0	0.00	0.00	0.00	0	0

Felt Pad	0	0.00	0.00	0	0	0
Thermal Insulation	0	0.00	0.00	0	0	0
TCA (solvent)	0	0.00	0.00	0	0	0
Water	-1154.62245	0.00	(0.01)	1,154.64	-0.01377415	1154.636223
Steam	0	0.00	0.00	0.00	0	0
Fuel	0	0.00	0.00	0.00	0	0
Air	0	0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0	0
Activated Carbon	0	(0.26)	0.26	0.00	0.261708769	0
CO	0	0.00	0.00	0.00	0	0
N2	0	0.00	0.00	0.00	0	0
H2O	0	0.00	0.00	0.00	0	0
H2	0	0.00	0.00	0.00	0	0
CO2	0	0.00	0.00	0.00	0	0
H	0	0.00	0.00	0.00	0	0
HO	0	0.00	0.00	0.00	0	0
NO	0	0.00	0.00	0.00	0	0
Al	0	0.00	0.00	0.00	0	0
O	0	0.00	0.00	0.00	0	0
CH4	0	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0	0
Ash	0	0.00	0.00	0.00	0	0

PBXN-109	25	33	34	35
TNAZ/Al	0	0.00	0.00	0.00
	-0.185	0.00	0.19	0.00

Solidification

Asphalt	-18.315	0.00	18.32	0.00	0.00
Bomb Case	0	0.00	0.00	0.00	0.00
Potting	0	0.00	0.00	0.00	0.00
Felt Pad	0	0.00	0.00	0.00	0.00
Thermal Insulation	0	0.00	0.00	0.00	0.00
TCA (solvent)	0	0.00	0.00	0.00	0.00
Water	0	(39.00)	0.19	38.81	0.00
Steam	0	0.00	0.00	0.00	0.00
Fuel	0	0.00	0.00	0.00	0.00
Air	0	0.00	0.00	0.00	0.00
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00
Activated Carbon	0	0.00	0.00	0.00	0.00
CO	0	0.00	0.00	0.00	0.00
N2	0	0.00	0.00	0.00	0.00
H2O	0	0.00	0.00	0.00	0.00
H2	0	0.00	0.00	0.00	0.00
CO2	0	0.00	0.00	0.00	0.00
H	0	0.00	0.00	0.00	0.00
HO	0	0.00	0.00	0.00	0.00
NO	0	0.00	0.00	0.00	0.00
Al	0	0.00	0.00	0.00	0.00
O	0	0.00	0.00	0.00	0.00
CH4	0	0.00	0.00	0.00	0.00
NH3	0	0.00	0.00	0.00	0.00
C2H4	0	0.00	0.00	0.00	0.00
C3H6	0	0.00	0.00	0.00	0.00
C2H6	0	0.00	0.00	0.00	0.00
C2H2	0	0.00	0.00	0.00	0.00
C3H8	0	0.00	0.00	0.00	0.00
CHN	0	0.00	0.00	0.00	0.00
C	0	0.00	0.00	0.00	0.00
Flue Gas	0	0.00	0.00	0.00	0.00
Total gaseous pollutant	0	0.00	0.00	0.00	0.00
Al2O3	0	0.00	0.00	0.00	0.00
Ash	0	0.00	0.00	0.00	0.00

Solid

Wastewater

	35	36	37	38	Waste	Emissions
PBXN-109	0	0.00	0.00	0.00	0	0
TNAZ/Al	0	0.00	0.00	0.00	0	0
Asphalt	0	0.00	0.00	0.00	0	0
Bomb Case	0	0.00	0.00	0.00	0	0
Potting	0	0.00	0.00	0.00	0	0
Felt Pad	0	0.00	0.00	0.00	0	0
Thermal Insulation	0	0.00	0.00	0.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0	0
Water	-38.8131313	0.00	38.81	0.00	38.81313131	0
Steam	0	0.00	0.00	0.00	0	0
Fuel	0	0.00	0.00	0.00	0	0
Air	0	0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0	0
Activated Carbon	0	(0.01)	0.01	0.00	0.008797453	0
CO	0	0.00	0.00	0.00	0	0
N2	0	0.00	0.00	0.00	0	0
H2O	0	0.00	0.00	0.00	0	0
H2	0	0.00	0.00	0.00	0	0
CO2	0	0.00	0.00	0.00	0	0
H	0	0.00	0.00	0.00	0	0
HO	0	0.00	0.00	0.00	0	0
NO	0	0.00	0.00	0.00	0	0
Al	0	0.00	0.00	0.00	0	0
O	0	0.00	0.00	0.00	0	0
CH4	0	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0	0
Ash	0	0.00	0.00	0.00	0	0

	34	39	40	41	42	Air Emissions	Solid Waste	
PBXN-109	0	0.00	0.00	0.00	0.00	0	0	0
TNAZ/Al	-0.185	0.00	0.00	0.00	0.00	0	0	0
Asphalt	-18.315	0.00	0.00	0.00	0.00	0	0	0
Bomb Case	0	0.00	0.00	0.00	0.00	0	0	0
Potting	0	0.00	0.00	0.00	0.00	0	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0	0	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0	0	0
Water	-0.18686869	0.00	0.00	0.00	0.00	0	0	0
Steam	0	0.00	0.00	0.00	0.00	0	0	0
Fuel	0	0	0.00	0.00	0.00	0	0	0
Air	0	0.00	?	0.00	0.00	0	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0	0
CO	0	0.00	0.00	0.06	0.00	0.06327	0	0
N2	0	0.00	0.00	0.04	0.00	0.043159619	0	0
H2O	0	0.00	0.00	0.00	0.00	0.003495619	0	0
H2	0	0.00	0.00	0.00	0.00	0.002516	0	0
CO2	0	0.00	0.00	0.00	0.00	0.002294	0	0
H	0	0.00	0.00	0.00	0.00	0.000183238	0	0
HO	0	0.00	0.00	0.00	0.00	0.000126857	0	0
NO	0	0.00	0.00	0.00	0.00	1.7619E-05	0	0
Al	0	0.00	0.00	0.00	0.00	1.7619E-05	0	0
O	0	0.00	0.00	0.00	0.00	1.7619E-05	0	0
CH4	0	0.00	0.00	0.00	0.00	0	0	0
NH3	0	0.00	0.00	0.00	0.00	0	0	0
C2H4	0	0.00	0.00	0.00	0.00	0	0	0
C3H6	0	0.00	0.00	0.00	0.00	0	0	0
C2H6	0	0.00	0.00	0.00	0.00	0	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	0	0
C3H8	0	0.00	0.00	0.00	0.00	0	0	0
CHN	0	0.00	0.00	0.00	0.00	0	0	0

Demil. Option 3

C	0	0.00	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00	0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0.07	0	0.069856
Ash	0	0.00	0.00	0.00	0.07	0	0.069856

Natural gas

mol%	Mwt	heat value MJ/M^3	Rio Arriba, Terrell, Tex	Stanton, KaSan Juan, MD	Olds Field, Cliffside, Texas					
Methane	16.043	37.57	96.91	45.64	67.56	77.28	52.34	65.8		
ethane	30.07	65.83	1.33	0.21	6.23	11.18	0.41	3.8		
propane	44.097	93.6	0.19		3.18	5.83	0.14	1.7		
butane	58.123	120.98	0.05		1.42	2.34	0.16	0.8		
pentane+	72.15	148.84	0.02		0.04	1.18	0.41	0.5		
CO2	44.01	0	0.82	53.93	0.07	0.8	8.22			
H2S	34.076	23.7		0.01			35.79			
N2	28.013	0	0.68	0.21	21.14	1.39	2.53	25.6	avg	SD (rel)
Mol wt:			16.62585	31.182	20.92126	21.28362	25.49289	20.44567	19.61024	10.79%
heating val	MJ/M^3		37.6	17.3	34.9	46.8	30	30.7	39.76667	12.81%
	MJ/KG		50.65847	12.42768	37.36678	49.25478	26.36029	33.63451	45.76001	13.03%
	0.0224M^3/mol		too high				too high	too low		
			CO2				Sulfur	heating		
			content for				content	value(?)		
			use							

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m³

Heating values for processed city natural gas:
source Perry 6 (1984)
averaged from table 9-14

Btu/scf 1049.571

Synopsis of table 9-14

[illegible]

Data from KO 2 (1964) for "modern mechanical method"	Gas		gas heat value				Tar data			
	Moisture	Heating valueBtu/lb	Gas yield scf/ton		gas lb/lb co		Gross heat value Btu/s Btu/ton co		Btu/lb coal Tar yield gal/ton	
	wet	dry	wet base	dry base	wet base	dry base	wet base	wet base	wet base	dry base
anthracite	0.051	10800	11380.4	123900	130558.5	138	145.4162	17098200	8549.1	9.5 10.01054
Belgian Co	0.026	11980	12299.79	120900	124127.3	150	154.0041	18135000	9067.5	1 1.026694
Adamslev	0.05	12080	12715.79	116100	122210.5	3.581182	165.6	174.3158	19226160	9613.08 21 22.10526

addesley coal ga	compositionMwt	vol%	O2 per mol mol O2 per mol gas

Component	Mass	Enthalpy	Enthalpy	Enthalpy
	kg	kJ	kJ	kJ
O2	44.01	6.7	0	0
CO2	44.01	6.7	0	0
H2O	31.9988	0	0	0
CO	28.016	25.3	0.5	0.1265
H2	2.0158	21	0.5	0.105
CH4	16.043	1.8	2	0.036
N2	28.013	45.2	0	0
Gas Mwt	23.41069		0.2675	mol O2 per mol gas
			1.277093	mol air to burn mol gas

0.9882 kg/m³
0.061691 lb/s cuf d=Mw/0.0224

Physical data
Density of T 75 lb/cuf Perry 6 (1984)
1200 kg/m³
10.01449 lb/gal

cf is volume in cubic feet at 60 Farenheit and 30" Hg KO 2 (1964)

density	lb/cuf	lb/gal	kg/m^3	Perry 6 (1984)
0.062428	0.008345		1	
7.480519		1	119.8264	
	1	0.133681	16.01846	

mass	ton (short - lb	kg	Perry 6 (1984)
1	2000		
2	204623	1	

Pressure	"Hg	N/m ²	atm	psia	Perry 6 (1984)
1	3376.9	0.033327	0.489775		
2.041754	6894.8	0.068046	1		
30.00533	101325	1	14.69586		
1					

Heat value MJ/m ³	btu/scf	Perry 6 (1984)
0.0373	1	

Energy	MJ	Btu	Perry 6 (1984) for steam table values
	0.001055	1	

molar dry air composition	Mwt	kg air per kg mass component
N2	0.78084	28.0134
O2	0.20946	31.9988
CO2	0.00033	44.01
Ar	0.00934	39.948
total	0.99997	28.96409

Coal type	Moisture	Sulfur	%dry	Heat value				
	%	%		Btu/lb	Btu/lbdry			
Sub bit C	26	0.3	0.41	8230	11121.62			
HV bit A	2.9	0.6	0.62	14170	14593.2	low sulfur coal heating value		
Sub bit B	22.2	0.5	0.64	9610	12352.19			
Brown Coa German - R	55	0.3	0.67	4830	10733.33			
Sub bit A	13.9	0.6	0.70	10330	11997.68	SD=	1295.775	0.108169
Meta Anthracite	9	0.7	0.77	10080	11076.92	Avg=	11979.16	
LV bit	2.9	0.8	0.82	14400	14830.07	median		
Anthracite	4.3	0.8	0.84	12880	13458.73		27.86352	MJ/kg
Lignite	36.8	0.9	1.42	7000	11075.95		dry base	
MV bit	2.4	1.5	1.54	14490	14846.31			
Semi anthracite	2.1	1.7	1.74	13700	13993.87			
HV bit B	6.7	2.6	2.79	12390	13279.74			
HV bit C	15.4	2.9	3.43	10740	12695.04			

bit=Bituminous

V=Volatility

L=low

M=Medium

H=high

Source: Kirk Othmer vol 4 1949