From: "D. Norman Diaz" <dnormdiaz@gmail.com>
To: Brianna Bergen <BBergen@waterboards.ca.gov>
CC: Patrice Copeland <PCopeland@waterboards.ca.gov>, Lauri Kemper <lkemper@w...
Date: 3/3/2010 10:51 AM
Subject: Lahontan submission for Nursery Products
Attachments: Bernardino ruling.pdf; Biofiltration &àe Reference.doc; Volatile Orga
nic Compounds and Pulmonary Function in the Third National Health and Nutri
tion Examination Survey, 1988û1994.pdf; ABT Odor Controàeport F
[1].pdf; abt-haskell.pdf

Please add these to the record.

Thanks for all the hard work on this project and issue.

Thanks

Norman

D. Norman Diaz
helphinkley.org
760 963-3585

OBJ OBJ OBJ OBJ OBJ

FILED
AUG 2 1 2009
By B. Rematore Dep. Clerk
SAN BERNARDINO COUNTY
SUPERIOR COURT, JOSHUA TREE DISTRICT

SUPERIOR COURT OF THE STATE OF CALIFORNIA

IN AND FOR THE COUNTY OF SAN BERNARDINO, JOSHUA TREE DISTRICT

HELPHINKLEY.ORG, an unincorporated association, Petitioner, vs. MOJAVE DESERT AIR QUALITY MANAGEMENT DISTRICT, Respondent.	Case No.: CIVBS800976 **STATEMENT OF DECISION AND ORDER THEREON**

On December 8, 2008, petitioners filed their Verified Petition for Writ of Mandate and Complaint for Injunctive and Declaratory Relief. Certification of the Administrative Record of Proceedings [AR] of the Mojave Desert Air Quality Management District [MDAQMD] was made on February 20, 2009. The Administrative Record was lodged with the court on May 21, 2009. A hearing on the causes of action, District's Setting of the Cost-Effectiveness Threshold for Particulate Control Measures Violates Health & Safety code § 39614 and is Arbitrary and Capricious and Entirely Lacking in Evidentiary Support (1st), District's Feasibility Findings for Composting Control Measures Are Arbitrary and Capricious and Entirely Lacking in Evidentiary Support (2nd) and Violation of the California

Environmental Quality Act, Public Resource Code §§ 21000 *et. seq.*, Unlawful

Exemption (3rd) was heard on June 22, 2009. The court advised counsel it would take the matter under submission, but that a decision would be delayed due to moving to the Joshua Tree courthouse and a scheduled vacation in July. After argument by all parties, the court took the matter under submission. The decision of the court follows:

MDAQMD'S EXEMPTION OF RULE 1133 FROM CEQA ANALYSIS

MDAQMD adopted Rule 1133 to comply with Heath & Safety Code § 39614. One of the general purposes was to limit emissions of volatile organic compounds [VOC] and ammonia from composting operations. (AR 009842.) Rule 1133 was also implemented "to assure the protection of the environment, specifically the proposed rule enhances the control of PM 10 emissions from certain composting and composting related operations where no such control has been previously imposed upon this particular source category." (AR 010056.) MDAQMD determined that the adoption of Rule 1133 was a project, but exempt from CEQA [California Environmental Quality Act] review "because it will not create any adverse impacts on the environment." (AR 010056.) MDAQMD found that proposed rule 1133 "has no potential to cause the release of additional air contaminants or create any adverse environmental impacts." (AR 010056.) MDAQMD determined that a Class 8 categorical exemption from CEQA was applicable to Rule 1133. (14 Cal. Code Reg. [C.C.R.] § 15308.) (AR 010056.)

Petitioner argues that respondent is not entitled to a categorical exemption.

Petitioner notes that amount of emissions reduced by implementation of Rule 1133 could not be quantified. (AR 002238) As discussed in oral argument, there is very little scientific research on commercial composting facilities and the amount of gases emitted under different management practices. A statement regarding a quantified reduction of emissions by implementation of Rule 1133 would be highly suspect without scientific proof. But a measure that reduces emissions in amount that cannot be quantified is still a measure "to assure the maintenance, restoration, enhancement, or protection of the environment." (14 C.C.R. § 15308.)The court finds that MAQMD is entitled to a categorical exemption.

The "best management practices" of Rule 1133 includes the requirement that a person engaged in composting operations "Scrape or sweep, at least once a day, all areas where Compostable [sic] Material is mixed, screened, or stored such that no Compostable [sic] Material greater than one inch (1") in height is visible in the areas scraped or swept immediately after scraping or sweeping, except for Compostable [sic] Material in process Piles or storgage Piles;." (AR 009850, 009851.) Another requirement is to "Maintain moisture content between 40 percent to 70 percent and test daily in Active Piles and monthly in Curing Piles, or Cover Active and Curing Piles within three hours of turning with one of the following: a. A waterproof covering; or b. At least six inches (6") of Finished Compost; or c. At least six inches (6") of soil." (AR 009851) The California Integrated Waste Management Board [CIWMB] submitted comments on the above practices. In reference to scraping or sweeping, CIWMB stated "Testimony at hearings in the San Joaquin Valley indicates this may not be achievable at most operations. Excessive sweeping may actually increase particulate issues. Keeping areas swept to 1" is not proven to reduce VOC or ammonia emissions." In reference to covering active or curing piles within three hours of turning, CIWMB stated, "Covering active compost piles with a waterproof cover may lead to anaerobic conditions, potentially resulting in more odors and emissions. Placing soil on top of compost piles may lead to anaerobic conditions, potentially resulting in more odors and emissions." (AR 008111.)

Petitioner argues that the comments submitted by CIWMB indicate that Rule 1133 is an exception to the exemption because "there is a reasonable possibility that the activity will have a significant effect on the environment due to unusual circumstances." (CEQA Guidelines, 14 C.C.R § 15300.2(c).) CIWMB's comment regarding excessive sweeping states what every person who has ever used a broom knows, the more you sweep, the more dust you stir up into the air. No definition of excessive sweeping is provided. The effect of excessive sweeping may increase particulate issues. Per CWIMB, covering compost piles with a waterproof cover or soil would potentially result in more odors and emissions. There was no quantifiable potential increase stated.

Accepting that there is a "fair argument" that Rule 1133, on the above basis, may have a significant effect on the environment (*Committee to Save the Hollywood Specific Plan v. City of Los Angeles* (2008) 161 Cal.App.4th 1168, 1187.) this court does not see how the comments by CWIMB constitute an "unusual circumstance" within the meaning of 14 C.C.R. 15300.2(c). In the court's view, there are two elements to the exception in 14 C.C.R. 15300.2(c), 1- a reasonable possibility that the activity will have a significant effect on the environment; 2- due to unusual circumstances. The court does not believe the second element has been negated by case law. (See *Banker's Hill, Hillcrest, Park West Community Preservation Group v. City of San Diego* (2006) 139 Cal.App.4th 249, 261, fn.1.) CWIMB sent a cover letter with it comments, stating therein, "We expect that the impact of Rule 1133 on these locally supported diversion efforts will be an important consideration for the MDAQMD staff and Board in evaluating the total environmental impacts of the proposed rule." (AR 008110.) If the court were to find CWIMB's comments an "unusual circumstance," then the exception to the exemption would be eliminated.

The primary complaint of petitioner is that MDAQMD's regulations of commercial composting facilities are not as stringent as neighboring air quality management districts. The South Coast Air Quality Management District [SCAQMD] requires conducting all active co-composting in an enclosed area that has an aeration system. (AR 005959-5960.) The San Joaquin Valley Air Pollution Control District [SJVAPCD], although not immediately adjacent to the MDAQMD, has different requirements depending on the size of the facility. (AR 006916.) Ultimately, SJVAPCD and SCAQMD (which covers the urban areas of Los Angeles and Orange County, and most of the Inland Empire) have adopted more stringent control measures to comply with Health & Safety Code § 39614 regarding emissions than MDAQMD's Rule 1133. While Rule 1133 provides regulations, where before there were none, nearby districts are enacting more stringent regulations. One does not need a degree in economics to realize that MDAQMD's area of jurisdiction is a simpler and cheaper place to commercially compost. In the court's view, this would be an "unusual circumstance" within the meaning of 14 C.C.R. 15300.2(c). In looking at the expense of emission control measures as estimated by the MDAQMD in other districts, it is clear to the court that Rule 1133 makes MDAQMD's area of jurisdiction a more cost effective locale to conduct composting. Rule 1133 provides a financial incentive for composting businesses to move to, or relocate to, locations within the MDAQMD. This scenario could cause adverse impacts to the environment, justifying an environmental review of Rule 1133. The court finds that an "unusual circumstance" is present taking Rule 1133 out of the categorical exemption.

MDAQMD'S COMPLIANCE WITH HEALTH & SAFETY CODE § 39614 COST-EFFECTIVE ANALSYSIS FOR PARTICULATE CONTROL MEASURES

Rule 1133 does not require use of a psuedo-biofilter. The $88 per ton calculation for best management practices as defined in Rule 1133 is not supported by the evidence since that analysis was based on the assumption that a pseudo-biofilter would be used. (AR 009826.) A substantiated calculation of the cost and benefits of the best management practices option has yet to be done. Health and Safety Code § 39614 requires an analysis to be done before the MDAQMD decides what rule to adopt, thus the MDAQMD abused its discretion in adopting Rule 1133.

ORDER

The court grants petitioners prayer for relief and orders a writ of mandate to be issued commanding the MDAQMD to (1) rescind Rule 1133 as adopted on October 27, 2008; (2) prepare an environmental Impact Report pursuant to Public

Resource Code § 20001, *et seq.*; (3) conduct a cost-benefit analysis of the "best management practices" option; and (4) adopt a rule that complies with Health and Safety Code § 39614. The MDAQMD is enjoined from implementing Rule 1133 unless and until the MDAQMD prepares an Environmental Impact Report and adopts a rule that complies with Health and Safety Code § 39614. The court retains jurisdiction, by way of return to the writ, over MDAQMD until the court has determined that MDAQMD has complied with CEQA. The court reserves jurisdiction over attorney's fees and costs. A request for attorney's fees and cost must be made by noticed motion.

The petitioners are to prepare a judgment and peremptory writ in conformity to this statement of decision. The court may modify or reject the proposed judgment and peremptory writ if it finds they are not in conformity with this statement of decision.

Dated:

JOHN P. VANDER FEER

John P. Vander Feer
Judge of the Superior Court

PROOF OF SERVICE BY MAIL

FILED
AUG 21 2009
By B. Trematore Dep. Clerk
SAN BERNARDINO COUNTY
SUPERIOR COURT, JOSHUA TREE DISTRICT

STATE OF CALIFORNIA)
)
COUNTY OF SAN BERNARDINO)

I am employed in the County of San Bernardino, State of California. I am over the age of 18 and not a party to the within action; my business address is 6527 White Feather Rd Joshua Tree, CA 92252

On August 21 2009, I served the foregoing document described as **Statement of Decision and order thereon** on the interested parties in this action by placing a true copy thereof enclosed in a sealed envelope addressed as follows:

CENTER ON RACE, POVERTY, & THE ENVIRONMENT
47 KEARNY STREET
SUITE 804
SAN FRANCISCO, CA 91408

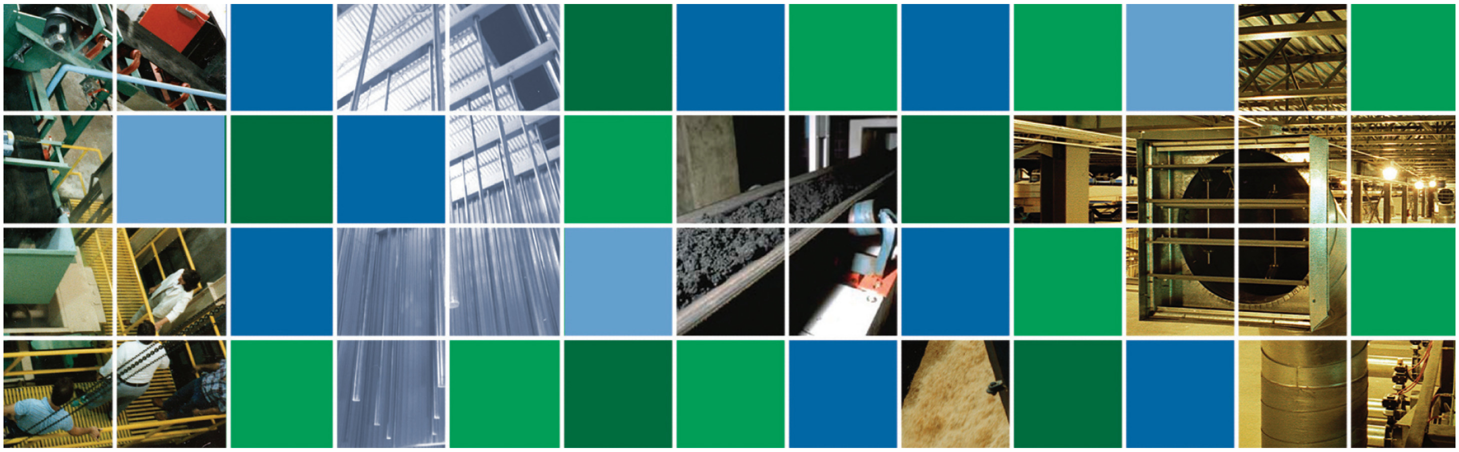
BEST BEST & KRIEGER
3750 UNIVERSITY AVE STE 400
P O BOX 1028
RIVERSIDE, CA 92502-1028

I caused such envelope with postage thereon fully prepaid to be placed in the United States mail at Joshua Tree, California.

I declare under penalty of perjury under the laws of the State of California that the above is true and correct.

Executed on August 21 2009, at Joshua Tree, California.

B. Trematore
Blanca Trematore
Administrative Assistant



Redland's AirLance™ Organic Waste Pasteurization Facility, 2007 Startup

Regional Organic Waste Recycling

ABT-Haskell presents an energy saving organic waste recycling service.

ABT-HASKELL

Composting of biosolids has proven to be one of the most accepted and successful methods for biosolids recycling over the last 20 years. Composting is also now the most cost effective when using the AirLance™ Process. The AirLance™ composting process reduces the land space and energy required by as much as 90% compared to conventional open or enclosed methods, and captures 99% of all odors.

ABT-Haskell is offering biosolids producers an opportunity to become part of a long term regional solution which is based on three simple principles 1) recycle biosolids close to the point of waste production, 2) do it in the most efficient manner possible, and 3) control odors and emissions so that it does not become a nuisance.

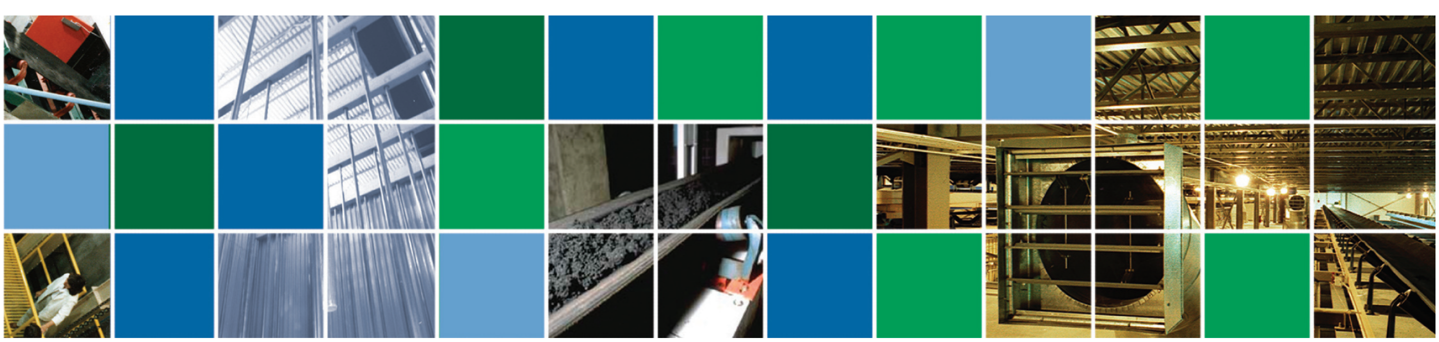
We are not offering an open pile stop gap composting service destined to be shut down because of negative environmental issues as population encroaches. The AirLance™ process is totally enclosed, and widely exceeds the most stringent SCAQMD environmental regulations, which allows it to be built in populated areas.

Our energy consumption to treat biosolids, and make it into a Class A product, is the lowest of any recycling process and a fraction of the cost of any heating or drying process. Our process also uniquely pasteurizes biosolids, by rasing the temperature to over 80 degrees centigrade. Our material handling is a non-contaminating process flow design; allowing us to make a safer, higher quality, EQ (Exceptional Quality) soil amendment compost product.

In addition, our service will also assist the community in meeting the California Integrated Waste Management Board landfill diversion regulations, currently 50% and planned @ 75%. It will also assit in reducing South Coast interstate truck traffic by millions of miles annually.

ABT-Haskell's first Regional Facility in Southern California is permitted and will be built in Redlands, CA. It is scheduled to go on line at the end of 2007. It is sized for maximum cost effectiveness at 100,000 wet tons per year capacity.

Entering into a long-term agreement with ABT-Haskell today will insure that you will have the lowest biosolids recycling cost today and tomorrow. We will design, build, finance, operate, and market all compost produced. No capital investment is required by waste producers, only a tipping fee contract.



Biosolids

With the continuing rise in energy and fuel cost, hauling biosolids further into the desert and into adjacent States for disposal, is no longer the most cost effective solution. Neither are energy intensive drying and heat treatment processes.

ABT-Haskell is offering the most energy efficient and proven approach to recycling biosolids that will stop the spiraling biosolids expense, now and into the future.

Compost Pasteurization

Nearly 20 years ago the first AirLance™ composting plant was built to process 100 wet tons per day. It is still operational with unmatched reliability and performance.

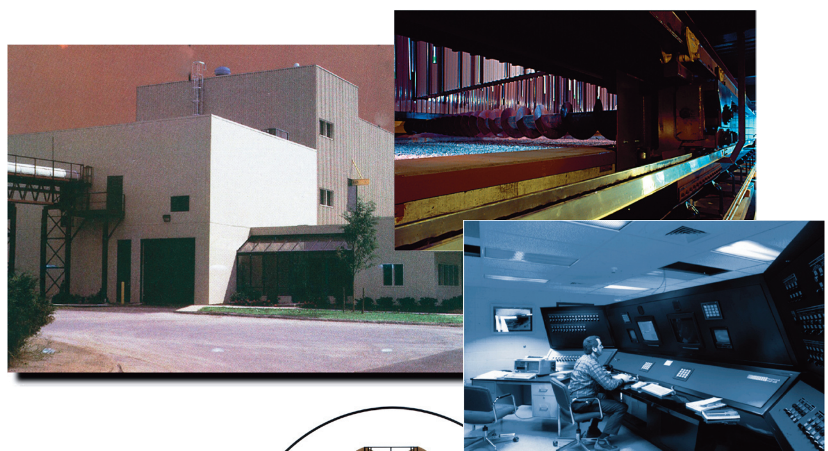
For years the AirLance™, process was more costly than trucking and land spread biosolids. This has changed with increasing trucking cost, higher energy costs, and the more stringent environmental regulations.

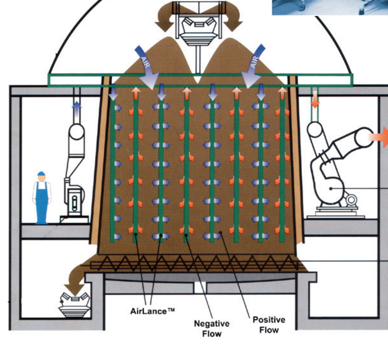
Trucking, land spreading, and open pile composting are no longer the cheapest methods to recycle biosolids.

The AirLance™ process has taken an agricultural recycling method and made it into an industrial process with a high degree of control.

This allows the biomass to reach pasteurization temperature, using only nature to develop the heat, and produces exceptional quality (EQ) compost.

Unlike open pile composting systems that use front-end loaders, material flow in our process assure that no finished compost can be contaminated by contact with non-pasteurized fresh mix or the equipment used to process it.





AirLance™ Organic Waste Pasteurization Process

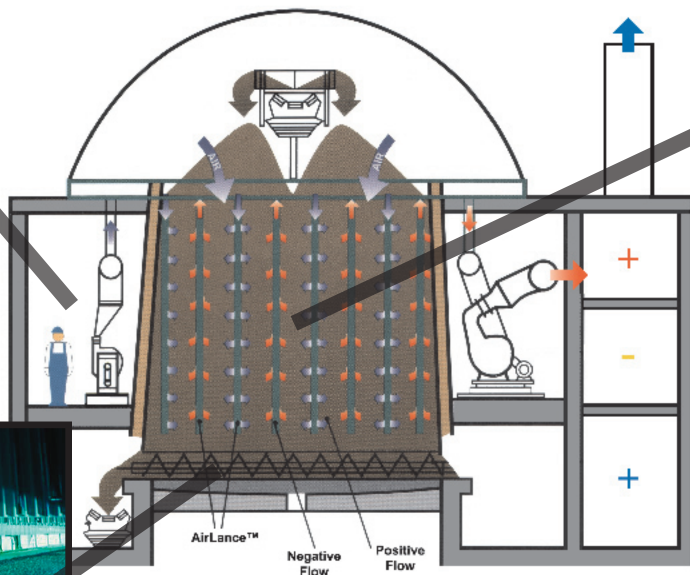
(section one cell)

Material Handling

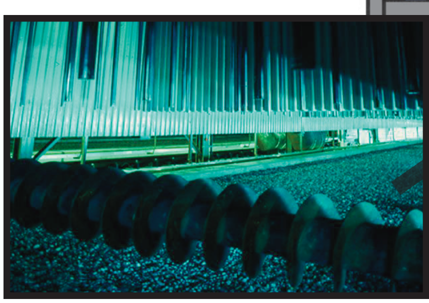
Trucked biosolids are unloaded into receiving hoppers and then automatically metered and mixed with a carbon source. The blended product is then loaded onto the top of composting cells to start the composting process. The cells are set inline, which allows a common loading and unloading system to be used. The number of cells we use determines the plant capacity. Gravity moves the composting material through the system. A single operator controls the complete process.
.
Once a day the unloading auger on the bottom moves through all the cells and removes a layer of compost off the bottom, and parks at the opposite end. Then the compost above moves down by gravity to fill the void left. (Similar to removing the bottom card from a deck of cards) The downward sliding movement causes all the compost to mix daily as it slides down to fill the void. Removing product makes space on the top to load daily fresh compost mix. This assures that all material is processed uniformly and that no material leaves the facility without being fully processed. It also assure the finished product is not recontaminated, which often occurs in conventional pile composting.

Empty Cell

Fans



Mixing / Blending



Auger in Empty Cell

Aeration

The compost is uniformly maintained in a highly aerobic state by the AirLance™ air injection system. This assures that the compost mix will reach higher pasteurization temperatures, accelerates the biological process, and assures uniform stabilization. The AirLances™ hang from multiple air plenum beams which are connected to low pressure fans on each end. 1) The low pressure fan on the left forces air into the compost biomass. 2) The fan on the right is simultaneously removing spent process air. 3) The direction of airflow is alternated. This maintains the biomass in a highly aerobic state accelerating the composting process. The spent process air removed is discharged as a hot saturated gas directly into a multi stage odor control system that is 95% plus efficient in odor and emissions removal.

AirLance™ Process

Low Energy

Low Manpower

Minimal Land Space

Totally Enclosed

Total Emission and Odor Control

A Good Neighbor

Our process uses a small fraction of the energy of alternate biosolids recycling/ stabilzation methods, even compared to other composting methods. Coupled with our ability to build close to where waste is produced, ABT-Haskell is able to offer a true long term solution that will only look better over time.

A Long Term Solution that brings costs under control

The low energy consuming Airlance™ Process is the most cost effective approach to biosolids recycling. In addition, we will be able to help the community meet the increasing diversion percentages of the California waste recycling regulations with our ability process to food waste and other organic wastes.

Redland's Regional Facility

Through a close a cooperative effort with the City of Redlands, we have developed a regional solution. The facility shown on the front cover is being built adjacent to the City of Redland's Waste Water Treatment Plant and landfill.

Permitting is in place and the facility is scheduled to come on line in 12-15 months. Presently we have limited available additional plant capacity, which we are offering to the nearest biosolids producers.

Proposal

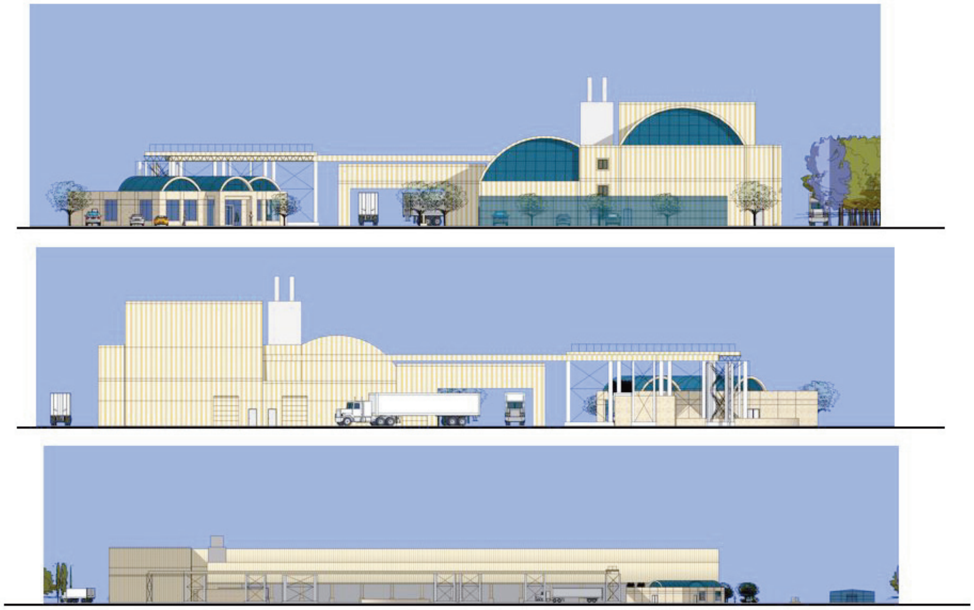
ABT-Haskell is offering a true long-term answer for biosolids recycling.

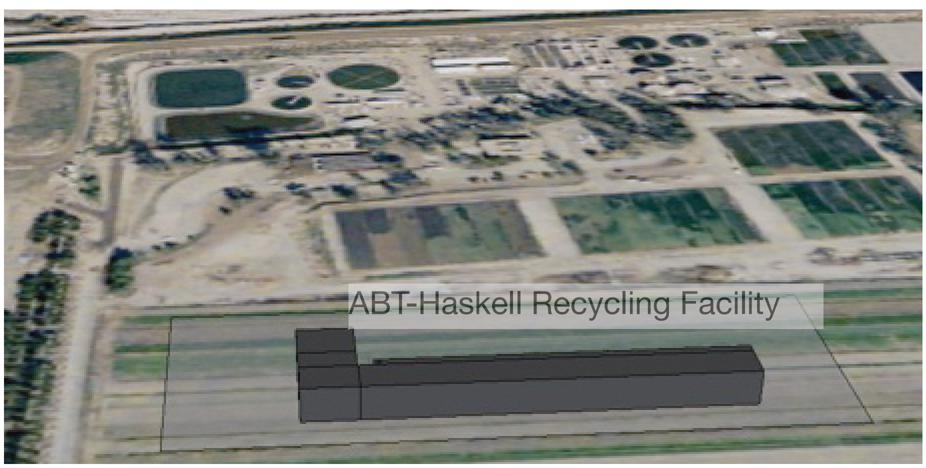
Our pricing will be competitive with present disposal cost, but more importantly, the ABT-Haskell Redlands Facility will stop the ever-spiraling cost increases caused by environmental regulations and increasing fuel and energy costs.

There is no investment required on your part. We will design, build, own, operate, and finance our facilities. All compost produced will be marketed by ABT-Haskell.

All we require is a put or pay tipping fee agreement which benefits both parties.

ABT-HASKELL

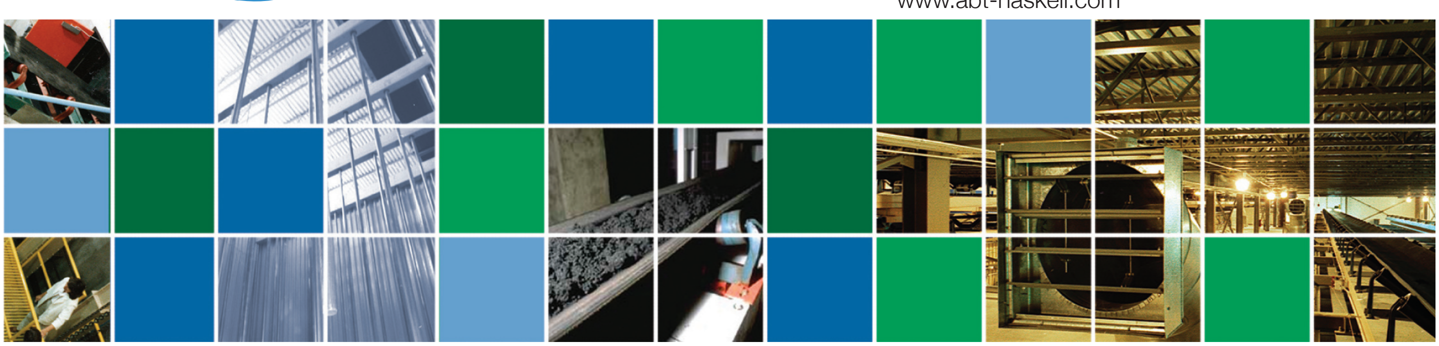




Aerial view of plant location

ABT-HASKELL

280 Business Park Circle, Suite 411
Saint Augustine, Florida 32095
904 940 5140 904 940 5977
www.abt-haskell.com



CONTROL AND EMISSIONS MODELING OF VOC, AMMONIA, AND ODOR FROM PROPOSED ABT-HASKELL AIRLANCE™ COMPOST FACILITY, REDLANDS, CALIFORNIA

PREPARED FOR:

ABT-Haskell
280 Business Park Circle, Suite 411
Saint Augustine, Florida 32095

PREPARED BY:

Soil/Water/Air Protection Enterprise
201 Wilshire Boulevard, 2nd Floor
Santa Monica, California 90401

June 8, 2005

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FIGURES

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A: SCAQMD Rule 1133.2
B: Odor Detections Limits Ruth
C: San Joaquin Report
D: ECO Report
E: ISCST3 Model Outputs

ABBREVIATIONS

AB	Assembly Bill
ABT-Haskell	ABT-Haskell, LLC
BACT	Best Available Control Technology
°C	degrees Celsius
cfm	Cubic Feet Per Minute
CH_3CH_2COOH	Propionic Acid
$CH_3CH_2CH_2COOH$	Butyric Acid
CH_3CH_2SH	ethyl mercaptan
CH_3SH	methyl mercaptan
CH_3COOH	Acetic Acid
CIWMB	California Integrated Waste Management Board
DMS	Dimethyl Sulfide
°F	degrees Fahrenheit
GLCs	ground-level concentrations
HS^-	Sulfide
H_2S	Hydrogen Sulfide
ISCST3	Industrial Source Complex Short Term Model 3
MEK	Methyl Ethyl Ketone
$\mu g/m^3$	micrograms per cubic meter
NaOH	Sodium Hydroxide
NH_3	Ammonia
SB	Senate Bill
SCAQMD	South Coast Air Quality Management District
SO_4^{2-}	Sulfate
SWAPE	Soil/Water/Air Protection Enterprise
TGNMOC	total gaseous non-methane organic compounds
TMA	Trimethyl Amine
VFA	Volatile Fatty Acids
VOC	Volatile Organic Compound

EXECUTIVE SUMMARY

ABT-Haskell, LLC, a joint venture of American Bio Tech and The Haskell Company (ABT-Haskell) retained Soil/Water/Air Protection Enterprise (SWAPE) to prepare a report on the potential odor emissions from a proposed enclosed, in-vessel organic waste (biosolids, foodwaste, greenwaste and waste wood) composting facility located approximately one-quarter mile north of Palmetto Avenue and Alabama Street in Redlands, California (the Site). The proposed facility will be an enclosed processing center and will serve as a valuable asset to San Bernardino County in meeting the requirements of California State Assembly Bill (AB) 939. The facility will also exceed the requirements of South Coast Air Quality Management District (SCAQMD) Rule 1133.2. Moreover, the site location selected by ABT-Haskell is ideal for the proposed facility, for it is situated in close proximity to an existing wastewater treatment facility that processes sludge in the drying lagoons for open-pile composting. It is proposed and anticipated that the ABT-Haskell facility will form a cooperative agreement with the City of Redlands (operator of the wastewater treatment plant) resulting in the removal of the sludge drying lagoons and improving local air quality. Additionally, the City of Redlands has proposed that the facility utilized untapped electrical energy production that could be developed from the wastewater treatment facility's anaerobic digesters due to the production of additional methane.

Assembly Bill 939, known as the Integrated Waste Management Act, was passed in 1989 because of the statewide increases in waste stream and decreases in landfill capacity. As a result, the California Integrated Waste Management Board (CIWMB) was established. AB 939 mandates a reduction of waste being disposed in the state and mandated that jurisdictions meet diversion goals of 50% by the year 2000. The pending Senate Bill 420 has been proposed to increase the solid waste diversion rate to 75% by 2015. As of 2005, the City of Redlands is diverting only 34% of their waste according to the CIWMB. ABT-Haskell's proposed facility will assist the City of Redlands and other municipalities within San Bernardino County in meeting this goal.

SCAQMD rule 1133.2 was passed in 2003 and mandates that all compost facilities in the South Coast Air Basin: (a) conduct all active co-composting within the confines of an enclosure, (b) conduct all curing using an aeration system that operates under negative pressure for no less than 90 percent of its blower(s) operating cycle; and, (c) vent the exhaust from the enclosure and the aeration system to an emissions control system designed and operated with a control efficiency equal to or greater than 80 percent, by weight, for VOC emissions and 80 percent, by weight, for ammonia emissions.

ABT-Haskell has developed a unique and patented enclosed AirLance™ Composting Technology that uniformly keeps the compost oxidized with a mean oxygen concentration of 19%, which is far higher than any other compost process. As a result of this and other improvements in the composting process, it is likely that the SCAQMD and the CIWMB will find that American Bio Tech's AirLance™ Technology is suited to become the Best Available Control Technology (BACT) for reducing compost odor and VOC emissions.

The AirLance™ Composting Technology was utilized and constructed at two compost facilities with outstanding success in New York and Connecticut. The proposed facility in Redlands, California will process approximately 100,000 wet tons of organic waste and up to 50,000 tons of waste wood annually, and will treat the VOC, ammonia and odor emissions with the most sophisticated compost emission scrubbing system available in the United States. The proposed scrubbing system will have: (1) a heat exchanger, which will cool the exhaust air and condense or trap most of the odorants and VOCs in solution; (2) a biofilter that will oxidize much of the sulfur compounds; (3) a sulfuric acid trap that will remove any ammonia or amines that get through the condensation trap; (4) a base trap that will capture any volatile fatty acids; and (5) a sodium hypochlorite treatment train that will further oxidize any odorants, including sulfur compounds, and kill any bacteria that pass through the system.

The proposed ABT-Haskell facility in Redlands will have 16 cells with an odor control system maintaining over a 60 second contact time. Two similar facilities have been constructed in New York (with 4.5 compost cells) and Connecticut (with 20 compost cells). The New York and Connecticut facilities had simple acid and base wet scrubbing systems with only 6 to 7 second contact times, which were sufficient to control odor emissions. The proposed ABT-Haskell facility in Redlands (with 16 compost cells) will a employ a wet scrubbing system with three additional treatment trains (heat exchanger/condensation trap, biofilter, and sodium hypochlorite misting system), in addition to the acid and base wet scrubbing treatment. The contact time at the Redlands Facility will be approximately 9 to 10 times greater than the previously constructed facilities that successfully controlled odor. The proposed Redlands facility, with its increased contact time and three additional odor control processes, will ensure that the potential to produce odors which may impact the community is *de minimus*.

To estimate potential ground-level concentrations of odorants from the facility, SWAPE compiled "worst-case" scenario compost emission data from studies performed by the SCAQMD on the San Joaquin Composting, Incorporated (Lost Hills, California) and EKO Systems (Corona, California) open-pile facilities. The term "worst-case" scenario is used because open-pile composting has been shown to be a mostly anaerobic (lacking oxygen) process that is not directly applicable to the highly aerobic AirLance™ process. With this in mind, emission factors were derived for ammonia, sulfur compounds, amine compounds, and VOCs above those outlined in SCAQMD Rule 1133.2. SWAPE estimated the potential ground-level concentrations of each of the odorants of concern (sulfur compounds, ammonia, amines, and VOCs) using the Industrial Source Complex Short Term Model 3 (ISCST3) for a variety of periods (1-hour, 12-hour, and annual average) as well as for a variety of control conditions (80% control of emissions, 95% control of emissions, 99% control of emissions, and 99.9% control of emissions). The modeling demonstrated that when the system is operational the proposed ABT-Haskell composting facility will have a *de mininus* impact upon the Redlands Community with regard to odor and volatile organic compounds emissions. In conclusion, the County of San Bernardino should embrace the ABT-Haskell project, for it will facilitate a process for local municipalities to meet the requirements for waste diversion from landfills under AB 939 and the project will have a *de minimus* impact upon the community. Moreover, the County of San Bernardino can be a leader in California for organic waste recycling by supporting such a sophisticated green industrial recycling technology.

1 INTRODUCTION

Soil/Water/Air Protection Enterprise (SWAPE) has prepared this report to assist in evaluation of odor emissions from the proposed ABT-Haskell organic waste composting facility located approximately one-quarter mile north of Palmetto Avenue and Alabama Street in Redlands, California (the Site).

This report presents the following information:

1. A literature review of biosolids compost odorants;
2. Description of the AirLance™ Technology that maintains an aerobic environment ;
3. Description of the proposed air scrubber system that eliminates emissions/odors;
4. Compost facility emissions inventory;
5. Local meteorological data; and
6. Modeling of potential offsite emission/odors from the proposed facility

1.1 COMPOSTING PROCESS

SCAQMD defines composting as an aerobic (oxygen dependent) degradation process by which organic wastes decompose under controlled conditions[1]. Composting typically involves the mixing of digested sewage sludge and other organic wastes with a bulking agent at an approximate 50-50 ratio. The final compost product is stable, free of pathogens, and can be used as a soil amendment and fertilizer. The bacterial breakdown of substrates also produces by-product organic and inorganic gases[2]. Emissions monitored in studies by SCAQMD include ammonia, amines, total sulfur compounds, methane, and total gaseous non-methane organic compounds (TGNMOC).

[1] SCAQMD. 1995. *Final Report: Emission Rate Characterization of Open Windrow Sludge Composting Operations*. South Coast Air Quality Management District. October, 1995. page 2

[2] SCAQMD. 1995. *Final Report: Emission Rate Characterization of Open Windrow Sludge Composting Operations*. South Coast Air Quality Management District. October, 1995 page 2

1.2 SCAQMD RULE 1133.2 -- EMISSION REDUCTIONS FROM CO-COMPOSTING OPERATIONS

Under SCAQMD Rule 1133.2 compositing facilities are to reduce volatile organic compounds (VOC) and ammonia (NH_3) emissions from co-composting operations[3]. A copy of Rule 1133.2 is attached as Appendix A. In addition to enclosing facilities, operators are required to have facilities in which:

(A)

(i) The inward face velocity of air through each opening in which air can enter the enclosure shall be a minimum of 100 feet per minute, unless the opening is equipped with a closure device that seals the opening in the event that the airflow direction changes.

(ii) The area of all openings in the enclosure through which air can enter the enclosure shall not exceed 2% of the surface area of the enclosure's four walls, floor, and ceiling.

(iii) The enclosure may be opened for brief time periods, not to exceed a total of 30 minutes per day for purposes of access or maintenance. These time periods do not need to be included in the face velocity determination or as an opening for the two percent criteria.

(iv) No measurable increase over background levels of ammonia or hydrocarbons outside the enclosure shall occur at any enclosure opening including any opening that occurs briefly for access or maintenance. A portable ammonia or hydrocarbon analyzer shall be used for these measurements. The portable ammonia analyzer shall be operated per manufacturer's instructions and calibrated with certified zero and 10 parts per million ammonia standards. The portable hydrocarbon analyzer shall be a flame ionization detector operated per manufacturer's instructions and calibrated with certified zero and 10 parts per million methane standards.

(B) Conduct all curing using an aeration system that operates under negative pressure for no less than 90 percent of its blower(s) operating cycle; and,

(C) Vent the exhaust from the enclosure and the aeration system to an emissions control system designed and operated with a control efficiency equal to or greater than 80 percent, by weight, for VOC emissions and 80 percent, by weight, for ammonia emissions.[4]

The practical result of the Rule is that all emissions from new composting facilities must be reduced by 80 percent (Paragraph (d)(2)). Paragraph (d)(3) of Rule 1133.2 allows existing composting facilities to reduce emissions to 70 percent.

Paragraph (d)(4) details baseline emission factors that may be used to determine the amount of VOC and NH_3 generated per ton of throughput (1.78 and 2.93 lbs per ton, respectively). These baseline emission factors may be used in lieu of specific emission factors when submitting a compliance plan for the proposed operations of new composting facilities. The emission factors represent non-controlled operations.

Conservative emission factors were derived from SCAQMD studies of open-pile composting systems for this assessment. This conservative approach will over-estimate the potential for emissions from the facility, providing a higher level of protection for the community by ensuring appropriate control measures are in place.

1.3 LANDFILL CAPACITY AND SOLID WASTE DIVERSION

Because of state-wide increases in solid waste streams and decreases in landfill capacity, the California legislature enacted Assembly Bill 939 (AB 939) and Senate Bill 1322 (SB 1322), known as the Integrated Waste Management Act, in 1989. The California Integrated Waste Management Board (CIWMB) was created as a result of this legislation and its authority and responsibilities were signed into law as the Integrated Waste Management Act of 1989.[5]

The Integrated Waste Management Act established a new approach to managing California’s solid waste stream, the centerpiece of which was a mandated 25 percent diversion of each city’s and county’s waste from disposal by 1995, and 50 percent

[3] SCAQMD Rule 1133.2 - Reductions From Co-Composting Operations *(Adopted January 10, 2003)*
[4] SCAQMD Rule 1133.2 - Reductions From Co-Composting Operations *(Adopted January 10, 2003)*

[5] CALEPA. 2003. The History of the California Environmental Protection Agency, The Integrated Waste Management Board. http://www.calepa.ca.gov/About/History01/ciwmb.htm.

diversion in 2000, along with a process to ensure environmentally safe disposal of waste that could not be diverted.[6]

The Integrated Waste Management Act, along with Title 14 and Chapter 15 of California's environmental regulations, also provided the foundation to put the state on course to comply with federal standards (Title 40, Code of Federal Regulations, Part 258, Subtitle D) for managing solid waste, including the design, construction and operation of landfills. In 1993, California became one of the first states to receive federal approval to assume authority over its solid waste activities, having actually exceeded the federal standards through the adoption of more stringent State regulations. Since then, the environmental performance of waste handling facilities in California have steadily improved and today rank the State as a world leader.[7]

The statewide solid waste diversion rate reached approximately 37 percent in 1999, continuing an upward trend that started with a rate of about 10 percent in 1989. Recent legislation, namely in Senate Bill (SB) 420, has been proposed to increase the solid waste diversion rate to 75% diversion by 2015.[8] ABT-Haskell's proposed facility will assist San Bernardino County in meeting this goal by recycling organic and carbonous (wood) wastes that are currently being landfilled.

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[6] CALEPA. 2003. The History of the California Environmental Protection Agency, The Integrated Waste Management Board. http://www.calepa.ca.gov/About/History01/ciwmb.htm.

[7] CALEPA. 2003. The History of the California Environmental Protection Agency, The Integrated Waste Management Board. http://www.calepa.ca.gov/About/History01/ciwmb.htm.

[8] Amended Senate Bill 420. March 29, 2005. http://info.sen.ca.gov/pub/bill/sen/sb_0401-0450/sb_420_bill_20050329_amended_sen.html

2 ODORANT LITERATURE REVIEW

2.1 ODORANT OVERVIEW

Odorous emissions from biosolids composting operations are believed to result primarily from sulfur and nitrogen compound emissions. Furthermore, ketones and volatile fatty acids have also been noted as odorant emissions from biosolids (Mosier et al., 1977).

Because each odorant has unique physical and chemical properties and odor characteristics or type (e.g. rotten vegetable, fishy), it is essential to correctly identify the odorants type in order to solve the problem and come up with an engineering solution. Moreover, it is important to identify individual chemicals responsible for the odor and conduct a health risk assessment in order to explain the relative risk to the community affected by the odor.

Odor has traditionally been evaluated using dilution-to-threshold olfactometry and via chemical analyses of common odorants. While dilution-to-threshold olfactometry is useful in determining the relative intensity of an odor, it does not address the relative offensiveness or character of the odor.

Odor emissions from biosolids composting are affected by (1) biosolids composition, (2) environmental variables, and (3) management practices. Different biosolids can have different chemical constituents, microbial communities, decomposition rates, odorous compounds, and odorant volatilization rates. Environmental variables that affect odor emissions include temperature, moisture, time, wind, redox potential, microorganisms, pH and structure (Miller, 1993).

2.2 ODORANT EMISSIONS FROM BIOSOLIDS

2.2.1 SULFUR EMISSIONS FROM BIOSOLIDS

Biosolids typically contain between 0.7 to 2.1% total elemental sulfur (Sommers et al., 1977), and some fraction of this sulfur volatilizes producing odor. Banwart and Bremner (1975) found that dimethyl disulfide accounted for 55-98% of total sulfur evolved from biosolids application to soil in aerobic conditions, which in many ways is similar to composting (Figure 2.1). Dimethyl disulfide is produced by many bacteria found in wastewater (Tornita et al., 1987) and fungi (Sunesson et al., 1995; Borjesson et al., 1993) and possesses a rotten cabbage odor with a low human detection limit of 0.1 micrograms per cubic meter (μg/m[3]) (Ruth, 1986).

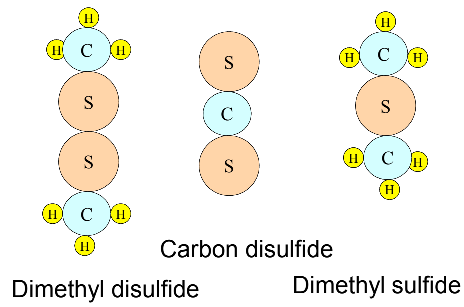


Figure 2.1: Sulfur Compounds

Dimethyl sulfide and carbon disulfide (Figure 2.1) are the other two most abundant sulfur emissions from biosolids application and composting in aerobic conditions (Banwart and Bremner, 1976). Dimethyl sulfide and carbon also possess a rotten cabbage smell, with human detection limits of 2.5 μg/m3 and 24.3 μg/m3 respectively (Ruth, 1986).

Sommers et al. (1977) characterized the forms of sulfur in 10 biosolids from different Indiana cities and found that approximately 65% of the sulfur was in the organic form. Organic-sulfur in biosolids can produce dimethyl disulfide, dimethyl sulfide and carbon disulfide (Banwart and Bremner, 1975). Sommers et al. (1977) found that approximately 35% total sulfur in biosolids was inorganic (with sulfide (HS-) accounting for 8.5% of total sulfur). Bacteria and fungi typically promote the methylation of HS- producing thiols and various methyl sulfides (Miller, 1993). The oxidation of methyl sulfides can produce dimethyl disulfide (Wilber et al., 1991).

Carbon disulfide has been documented to form in both aerobic and anaerobic environments via microbial decomposition of sulfide containing amino acids found in protein. Banwart and Bremner (1975a) reported that carbon disulfide emissions resulted from decomposition of cysteine, cystine, homocystine, lanthionine, and Djenkolic acid.

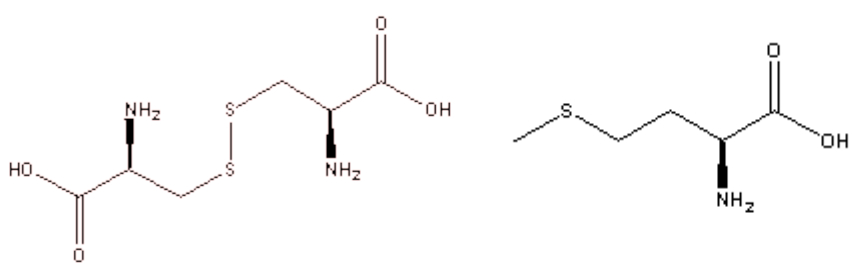
Hydrogen sulfide (H_2S) has not been found to volatilize following biosolids application to soil in aerobic conditions (Banwart and Bremner, 1976), and is not found in aerobic biosolids composting. Biosolids often have a pH around 8.5, and at this pH H2S (pKa=7.04) deprotonates to sulfide (HS-), a non-volatile ionic molecule. Furthermore

H2S is a polar molecule with a structure similar to water, and is held in solution via hydrogen bonding. In addition, H2S is readily oxidized in aerobic conditions (Paul and Clark, 1996). Bacteria and fungi can also remove HS- by promoting methylation, producing thiols and various methyl sulfides (Miller, 1993).

Finally, methyl mercaptan (CH_3SH) and ethyl mercaptan (CH_3CH_2SH) are not detected resulting from biosolids in aerobic conditions (Banwart and Bremner, 1976). Although these compounds are present in the ambient air near wastewater facilities, these compounds are highly reactive and are easily catalyzed forming disulfides (Huang, 1994).

Dimethyl sulfide (DMS) has been documented to form in both aerobic and anaerobic environments via microbial decomposition of sulfur containing amino acids found in protein. Banwart and Bremner (1975) reported that dimethyl sulfide emissions resulted from methionine and homocystine. The degradation of sulfur containing amino acids, specifically cystine and methionine can produce hydrogen sulfide and DMS under anaerobic conditions (Oho et al, 2000, Persson 1992).

Amino acids are the monomers of protein and both cysteine and methionine have been shown to be present in extracted from activated sludges and anaerobically digested sludges (Higgins and Novak, 1997). This mechanism would likely entail the sequential step of the breakdown of protein for form peptides and degradation of peptides for form these free amino acids which would then be broken down to from volatile sulfur compounds.



Cystine Methionine

Figure 2.2: Amino Acids

2.2.2 NITROGEN EMISSIONS

Ammonia and trimethyl amine comprise most of the odorous nitrogen emissions from biosolids composting (Figure 2.2). Ammonia produces a pungent medicinal odor with a human detection limit of 26 $\mu g/m^3$ (Ruth, 1986), while TMA produces a fishy odor with a human detection limit 100 times lower at only 0.8 $\mu g/m^3$ (Ruth, 1986).

The major biological forms of nitrogen include amino acids and nucleic acids (Paul and Clark, 1996). These materials are present in wastewater and mineralize, resulting in NH_4^+ formation (Mitsch and Gosselink, 1993). Anaerobically digested biosolids typically contain between 3 to 6% nitrogen, and 40 to 75% of nitrogen is organic-nitrogen, while the balance is NH_4^+-N (Kardos et al., 1977). Typically, the NH_4^+ ion in biosolids quickly deprotonates resulting in volatile NH_3. Ammonia emissions are reported to be highest during the first several days after biosolids application and then significantly drop off (Harmel et al., 1997). Furthermore, Beauchamp et al. (1978) found that temperature was the most important variable explaining NH_3 volatilization during the first few days after application.

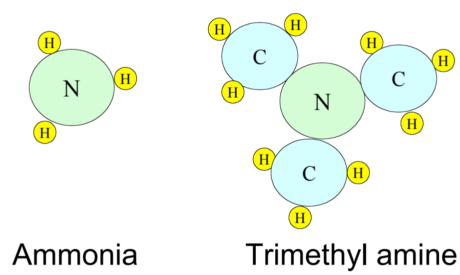


Figure 2.3: Nitrogen Compounds

Hutchenson et al. (1982) measured NH_3 and amine emissions above a cattle feedlot, finding that the NH3-N flux was equal to 99% of the total nitrogen-flux, while the amine flux was equal to approximately 1% of total nitrogen-flux. Of the amines, TMA was always present in highest concentrations and exceeded the sum of other atmospheric amines by sevenfold. Trisubstituted amines (such as TMA) are apparently less readily attacked than are monoamines by the microorganisms active in fecal protein catabolism (Thimann, 1963).

Schade and Crutzen (1995) investigated N emissions from chicken, cow, horse, and swine feces and found that the NH3-N flux was 99.3% of the N-flux, while amines were approximately 0.7% of the N-flux. The amine emissions consisted almost entirely of methyl amines and correlated with NH3 emissions. Of the amines, TMA exceeded the sum of other atmospheric amines by three times.

2.2.3 KETONE EMISSIONS

Humans are not particularly sensitive to acetone and methyl ethyl ketone (MEK), with human detection limits of 1100 $\mu g/m^3$ (Ruth, 1986) and 750 $\mu g/m^3$, respectively (Ruth, 1986). While the sweet solvent-like odors of ketones may not be perceived as unpleasant, mixed with other odorants they contribute to a generally unpleasant odor.

Ketones can be formed via anaerobic decomposition of cellulose, starch, hemicellulose, and pectins (Mosier et al., 1977). Clostridium sp. bacteria have been identified as acetone producers (Holdemand and Moore, 1973; El Ammouri, 1987; Martin, 1983) and are obligate anaerobes (Killham, 1994). Furthermore, Clostridium sp. has been identified in wastewater and biosolids (Gold et al., 1992; Garcia and Bacares, 1997; Edwards et al., 1998). Van Durme et al. (1992) identified a number of ketones including acetone and methyl ethyl ketone (MEK) as odorant emissions from composting of biosolids (Figure 2.4)

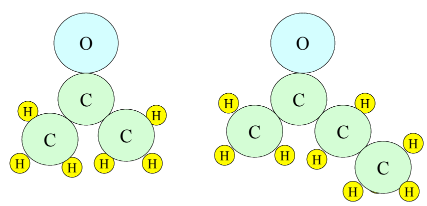


Figure 2.4: Ketones

2.2.4 VOLATILE FATTY ACID EMISSIONS

During wastewater treatment and the anaerobic digestion process, starch, cellulose and hemicellulose are broken down by acid forming bacteria into short chain volatile fatty acids (VFAs) (Figure 2.5). Methanogens, or methane producing bacteria, then convert VFAs into methane (Paul and Clark, 1996).

Thermophillically digested biosolids (50° to 55°C) usually produce more VFA emissions than mesophillically digested biosolids (30° to 35°C), resulting from both higher temperatures and shorter anaerobic digester detention times (Cecil et al., 1992). Volatile fatty acids seldom contribute to the odor from aerobic biosolids at room temperature, for the boiling points for acetic, propionic, and butyric acids are 118, 141, and 164°C, respectively. However, researchers have detected volatile fatty acids during heating of biosolids. For instance, acetic acid was the major VFA produced when diluted biosolids were heated to 121°C (Badawi, 1992). Acetic acid was found in high concentration when sewage sludge was pyrolized at 250°C (Conesa et al., 1998).

According to Mackie (1994), the greater the chain length and the more branching that exists in low molecular weight VFAs, the greater the offensiveness of the odor associated with these acids. For instance, the human detection limits for acetic (CH_3COOH), propionic (CH_3CH_2COOH), and butyric ($CH_3CH_2CH_2COOH$) acids are 2500, 84, 1 $\mu g/m^3$ respectively (Ruth, 1986).

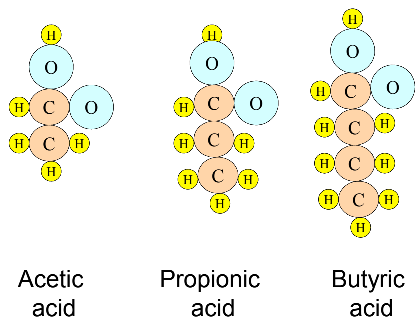


Figure 2.4: Volatile Fatty Acids

2.2.5 ODORANT DETECTION LIMITS

For a person to smell something, air containing odorant molecules must reach a tiny cluster of specialized nerve cells called olfactory neurons. Each nasal cavity has 5 million olfactory neurons, which can perceive 4000 different odors. However, the average individual can only name a handful of odors. This limitation is a result of an individual's inability to name a substance, rather than failure to detect the difference between odors (Ruth, 1986).

A classical definition of odor threshold is the minimum concentration of an odorant which produces a noticeable change in the odor of the system (Ruth, 1986). Odorous samples are presented to panelists by starting with a blank and increasing odorant concentration until odor is perceived. The lowest reported published human detection limits for various odorous compounds are listed in Table 2.1.

It must be noted that data in Table 2.1 are for single odorants when no other odorants are in the air. When two different odorants are introduced into a system, they can act in a synergistic, additive, independent, or counteractive way. To date, mixtures of chemicals have received very little study (Ruth, 1986) (Appendix B).

Table 2.1: Published human detection limits for biosolids compost odorants

Compound	Odor Character	Low Odor Detection Limit (ug/m^3)	High Odor Detection Limit (ug/m^3)	Source
Dimethyl Disulfide	Rotten Cabbage	0.1	246	Ruth, 1986
Hydrogen Sulfide	Rotten Eggs	0.7	14	Ruth, 1986
Dimethyl Sulfide	Rotten Cabbage	2.5	50	Ruth, 1986
Carbon Disulfide	Rotten Cabbage	24	23100	Ruth, 1986
Ammonia	Medicinal	26.6	39600	Ruth, 1986
Trimethyl Amine	Fishy	0.8	0.8	Ruth, 1986
Methyl Ethyl Ketone	Sweet	750	737	Ruth, 1986
Acetone	Sweet	47466	1613860	Ruth, 1986
Acetic Acid	Vinegar	2500	250000	Ruth, 1986
Propionic Acid	Vinegar	84	60000	Ruth, 1986
Butyric Acid	Vinegar	1	900	Ruth, 1986

3 PROPOSED DEVELOPMENT USING AIRLANCE™ TECHNOLOGY

3.1 ABT-HASKELL DEVELOPMENT

ABT-Haskell is proposing to develop a completely enclosed organic waste composting facility in Redlands, California, utilizing AirLance™ Technology that will process approximately 100,000 wet tons of organic waste annually. Additionlly, the proposed facility will process between 25,000 and 50,000 tons of waste wood (green-waste) annually. The site selected by ABT-Haskell is ideal for the proposed facility, for it is in close proximity to a wastewater treatment facility with sludge drying lagoons, and is bordered by two solid waste landfills. It is anticipated that this proposed facility will result in removal of the sludge drying lagoons, thus improving local air quality. The facility will process compost in less time, produce fewer emissions, and subsequently fewer odors (detailed below).

The City of Redlands wastewater treatment facility is located at the north end of Nevada Street, on approximately 50 acres adjacent to the Santa Ana River (northwest of the proposed facility). The City of Redlands facility has been modified to provide secondary Wastewater treatment. Wastewater solids are settled in large tanks and then removed, dried and then composted at OneStop Landscape, an open pile composting facility located in Redlands, CA. The liquid portion is combined with "safe to humans" bacteria and processed further as the bacteria consume over 95% of the water born pollutants. The processed water is then percolated back into the groundwater basin. The City of Redlands facility has the ability to process 9.5 million gallons of wastewater per day, and is currently processing about 6 million gallons per day.

The ABT-Haskell plant will be equipped with an emission scrubbing system capable of treating VOC, ammonia, and odor emissions in excess of the requirements for emission controls as outlined in AB 1133.2. The facility will achieve emission controls in excess of 99% (detailed in section 4.0). The proposed scrubbing system will have: (1) a heat exchanger which will cool the exhaust air and condense or trap most of the odorants and VOCs in solution; (2) a biofilter that will oxidize much of the sulfur compounds; (3) a sulfuric acid trap that will remove any ammonia or amines that get through the condensation trap; (4) a base trap that will capture any volatile fatty acids; and (5) a sodium hypochlorite treatment train that will further oxidize any odorants including sulfur compounds and kill any bacteria that get through the system.

3.2 AIRLANCE TECHNOLOGY

The AirLance™ Process allows composting to be maintained at a maximum biological rate with minimal material handling and low energy consumption. Composting inside the cubical cells remains above 55 degrees Celsius for the full composting period, assuring that the composting process is rapid and cost effective. The compost remains in the system for 14 to 28 days, which is determined by the waste processed, and it leaves as a finished product.

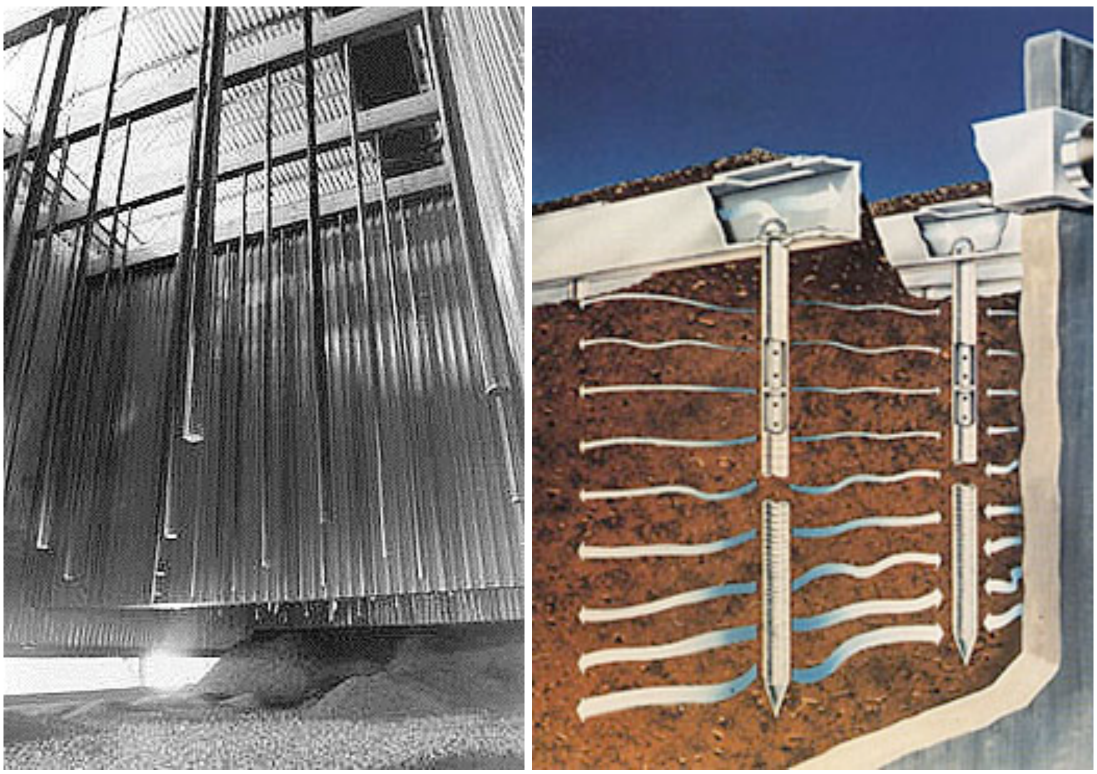


Figure 3.1 & 3.2: The figure on the left shows the Air Lance technology from the bottom of each cell. The figure on the right demonstrates how the air flow through the compost keeps the cells oxygenated

According to the designers, advantages of the AirLance™ Process over open-pile systems include:

1. Reduction in Material Handling

In the AirLance™ System the compost biomass mix is only handled twice during the composting process, loading and unloading the cell. The AirLance™ process does not require the compost to be re-piled and moved numerous times for curing, sorting, and screening.

2. Aerobic BioMass

The AirLance™ Process maintains aerobic conditions by uniformly aerating evenly throughout the biomass to maximize the rate of organic waste stabilization. What is often not realized is that within 20 minutes after making a conventional compost pile, the main mass is depleted of oxygen and the microbes are dying. The center only stays warm because it is well insulated. Daily mixing of windrow composting piles releases anaerobic odors, re-aerates, releases heat, and restarts the process. This is why windrow composting takes considerably longer to complete the process. Static pile composting doesn't significantly change this problem. Attempting to aerate a large pile from the bottom is not very effective. Fluid (air) will always find the path of least resistance and short circuit.

3. Process Time

In the AirLance™ Process all compost is contained inside the system for the full 14 to 28-day composting period. The compost is maintained at 55 to 80 degrees centigrade over the full period, assuring that the compost is a finished stabile product when it leaves the system. Many composting systems only contain the compost in their systems for a few days, and then they pile the compost outside to finish the process. Only because containing the compost for a full 14 to 28 days would make their systems far too expensive to build and operate.

4. Capacity Rating

The AirLance™ Process allows all compost to be loaded into the system as a fine and uniform product. Large chunks of waste to build pore space for aeration are not required. Large pieces only have to be removed later adding another step in the process. This also means that 100% of the product leaving the AirLance™ composting cell is finished, ready for use, and it does not require further screening or recycling.

When finished compost from a windrow composting operation needs to be re-screened to remove foreign material after the process; it also means you have wasted valuable space in the composting operation with non-compost product. A compost process should be capacity rated by the amount of compost it produces, not by what was loaded into the system, and later removed.

More important this means the AirLance™ process can process 2 to 4 times more compost in an equivalent size system. This unique ability of the AirLance™ System to compost a fine material becomes a significant economic advantage in the big picture.

5. Daily Mixing

In the AirLance™ Process all compost is remixed daily. By using gravity to accomplish the mixing action, it requires only 5 to 10% of the energy of other processes to mix. Compost is mixed daily without fear of extensive heat loss.

6. Material Handling Efficiency

The high material handling efficiency of the AirLance™ Process design frequently uses less than 10% of the time and energy for loading / unloading of other composting processes.

7. Aeration Efficiency

The high efficiency of the AirLance™ Aeration Process design greatly reduces energy cost for aeration, ventilation, and odor control compared to other composting processes.

8. Odor Control

The high efficiency of the AirLance™ Aeration Process design simplifies odor control. It reduces the volume of odorous air and allows for a much smaller and more effective odor control system to be built.

3.3 OXYGEN CONTENT AND ODOR EMISSIONS

Maintaining an oxygen content above 15% greatly reduces odor during composting. Ambient air contains 21% oxygen. When the oxygen content in a compost pile falls below 15% reduced sulfides form via reduction of sulfur, and volatile fatty acids, ketones and aldehydes form via incomplete oxidations of cellulose and other carbon substrates. Unfortunately, most composting processes have very low oxygen concentrations.

Dr. Mike Robe (Robe, 2005) conducted experiments measuring the oxygen content throughout an windrow composting facility and found that the oxygen content dropped to below 5% within one hour of composting (Figures 3.3 and 3.4). Hence one can assume that the center of most windrow composting piles are anaerobic forming odorous reduced sulfides, ketones, aldehydes.

The AirLance™ Aeration Process eliminates this anaerobic process and effectively eliminates the formation of the most odorous compounds found in emissions from composting. Instead of reduced sulfides forming via anaerobic conditions, sulfate (SO_4^{2}) forms that is a non-volatile ion with no odor. Moreover, with sufficient oxygen, cellulose can break down all the way to CO_2 and H_2O rather than forming intermediate ketones, aldehydes and fatty acids.

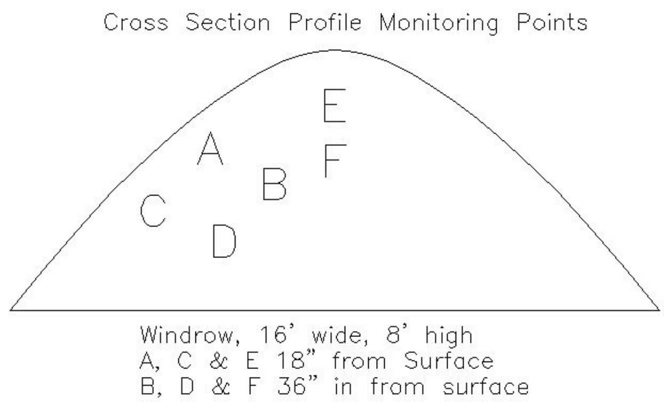


Figure 3.3: Cross Section Of Typical Windrow Composting (Robe, 2005)

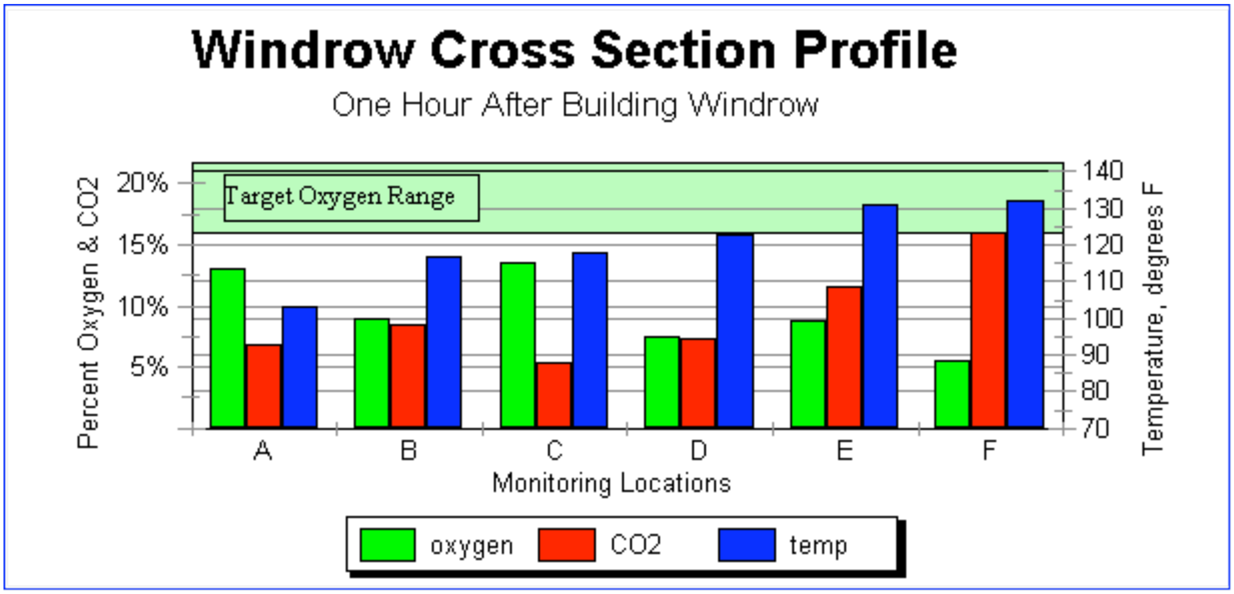


Figure 3.4: Oxygenc and Carbon In Relation To Cross Section In Figure 3.3 (Robe, 2005)

4 AIR SCRUBBER SYSTEM THAT ELIMINATES EMISSIONS/ODORS

ABT-Haskell has proposed to construct the largest and most advanced odor treatment system ever designed in the compost industry. The proposed air scrubbing system will have several stages and more than sixty (60) seconds of contact time. The treatment processes will include: (1) a heat exchanger and condensation trap; (2) a biofilter; (3) sulfuric acid wet scrubber; (4) a sodium hydroxide base wet scrubber; and (5) a sodium hypochlorite oxidizing wet scrubber. Each of these treatment processes are described below.

The proposed ABT-Haskell facility in Redlands will have 16 cells with an odor control system maintaining over a 60 second contact time. Two similar facilities have been constructed in New York (with 4.5 compost cells) and Connecticut (with 20 compost cells). The New York and Connecticut facilities had simple acid and base wet scrubbing systems with only 6 to 7 second contact times, which were sufficient to control odor emissions. The proposed ABT-Haskell facility in Redlands (with 16 compost cells) will a employ a wet scrubbing system with three additional treatment trains (heat exchanger/condensation trap, biofilter, and sodium hypochlorite misting system), in addition to the acid and base wet scrubbing treatment. The contact time at the Redlands Facility will be approximately 9 to 10 times greater than the previously constructed facilities that successfully controlled odor. The proposed Redlands facility, with its increased contact time and three additional odor control processes, will ensure that the potential to produce odors which may impact the community is *de minimus*.

4.1 HEAT EXCHANGER AND CONDENSATION TRAP

The heat exchanger will reduce the temperature of the influent to the scrubbing system from approximately 130 degrees Fahrenheit (°F) to 90 °F. Dew point is the temperature at which condensations forms. This component of the treatment system is designed to remove 99.9% of the ammonia. When air comes in contact with a surface that is at or below its dew point temperature, condensation will form on that surface. With a 100 percent relative humidity at 90 °F, all gasses should condense to liquid and fall out in the condensation trap.

4.2 BIOFILTER

A biofilter will be installed in line to oxidize a wide variety of odorants including any nitrogen, sulfur, ketone, and aldehyde compounds that get through the system. The biofiter polypropylene labyrnith with filter media allowing for bacterial populations to accumulate.

4.3 SULFURIC ACID

Sulfuric acid wet scrubbing will be used to trap any amines or ammonia that get through the heat exchanger and condensation trap, although the ammonia and amine concentrations should be at non-detect. Sulfuric acid reacts with ammonia gas (NH_3) by donating a proton, forcing ammonia gas to become ammonium (NH_4^+) that is then in solution as an ion. The sulfuric acid will be fine misted into the system.

4.4 SODIUM HYDROXIDE

Sodium hydroxide (NaOH) traps volatile fatty acids. The sodium hydroxide will be fine misted into the system.

4.5 SODIUM HYPOCHLORITE

Sodium hypochlorite or bleach will be used as an oxidizing agent for sulfur compounds, and any other odorants or bacteria that come into contact with this oxidizing agent. The sodium hyperchlorite will be fine misted into the system.

5 EMISSIONS INVENTORY

Potential emissions from the facility were derived from source test reports of open-pile composting systems completed by the SCAQMD. SCAQMD defines composting as an aerobic (oxygen dependent) degradation process by which organic wastes decompose under controlled conditions.[9] The final product is stable, free of pathogens, and can be used as a soil amendment and fertilizer. The bacterial breakdown of substrates also produces by-product organic and inorganic gases.[10] Emissions monitored in studies by SCAQMD include ammonia, amines, total sulfur compounds, methane, and total gaseous non-methane organic compounds (TGNMOC).

Methane is produced during the anaerobic decomposition of organic material.[11] According to SCAQMD, the amount of methane generated is a function of the fraction of the total waste that is available for anaerobic bacteria, temperature, and moisture.[12] For windrow operations, methane production is highest in the first 21 days of composting. Since the AirLance™ method involves aerobic composting, methane is not produced in the system. Therefore, methane will be excluded from the emission inventory for the proposed plant.

For the SCAQMD studies, sampling was performed in order to inventory emissions from sludge composting operations in the South Coast Air District in order to evaluate the impact of the operations for possible inclusion to the Air Quality Management Plan (AQMP).[13,14] The facilities had been volunteered for sampling by the owners. Emissions were collected from the piles at various points in the composting cycle. According to the reports, the days for sampling were chosen to represent the beginning

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[9] SCAQMD. 1995. *Final Report: Emission Rate Characterization of Open Windrow Sludge Composting Operations*. South Coast Air Quality Management District. October, 1995. page 2

[10] SCAQMD. 1995. *Final Report: Emission Rate Characterization of Open Windrow Sludge Composting Operations*. South Coast Air Quality Management District. October, 1995 page 2

[11] SCAQMD. 1995. *Final Report: Emission Rate Characterization of Open Windrow Sludge Composting Operations*. South Coast Air Quality Management District. October, 1995. page 12

[12] SCAQMD. 1995. *Final Report: Emission Rate Characterization of Open Windrow Sludge Composting Operations*. South Coast Air Quality Management District. October, 1995. page 12

[13] SCAQMD. 1996. *Source Test Report 96-0007/96-0008/96-0009 Conducted at San Joaquin Composting Inc, Holloway Road, Lost Hills, California, Characterization of Ammonia, Total Amine, Organic Sulfur Compound, and Total Non-Methane Organic Compound (TGNMOC) Emissions from Composting Operations*. South Coast Air Quality Management District. November 16, 1996.

[14] SCAQMD. 1996. *Source Test Report 95-0032/96-0003 Conducted at EKO Systems 8100-100 Chino-Corona Road, Corona, California, 91720, Characterization of Ammonia, Total Amine, Organic Sulfur Compound, and Total Non-Methane Organic Compound (TGNMOC) Emissions from Composting Operations*. South Coast Air Quality Management District. May 16, 1996.

of the composting cycle, the peak temperature day, and the ending day of the composting cycle. The reported emissions were for windrows at the sites since sampling for curing piles emissions was not performed. Piles at the site were turned one to three times per week and samples were collected after turning had been completed. The turning process can release large quantities of emissions and sampling was performed after turning was completed.

The first study of the San Joaquin Composting, Incorporated[15] facility located on Holloway Road, in Lost Hills, California, measured the emission profile of the operation over the composting cycle. The facility composted piles of dewatered sewage sludge and green waste. Emissions were collected from the piles on days 3, 45, and 57 of the composting cycle. The estimated facility wide emissions did not include curing pile emissions and were calculated using the average of the three windrow ages[16].

Table 5.1: San Joaquin Composting, Incorporated Facility Average Emissions for 3, 45, and 57 Day Piles:

Chemical	Emissions per ton of Compost Mix
Ammonia	2.81 lbs/ton mix
Amines	0.19 lbs/ton mix
Total Sulfur Compounds	0.22 lbs/ton mix
TGNMOC	3.12 lbs/ton mix

The second study performed by SCAQMD was of the EKO Systems[17] facility located at 8100-100 Chino-Corona Road, Corona, California, measured the emission profile of the operation over the composting cycle. The facility composted piles of dewatered sewage sludge and manure. Emissions were collected from the piles on days 2, 20, and 50 of the composting cycle. According to the report, the days for sampling were chosen as the beginning of the composting cycle, the peak temperature day, and the ending day of

[15] SCAQMD. 1996. *Source Test Report 96-0007/96-0008/96-0009 Conducted at San Joaquin Composting Inc, Holloway Road, Lost Hills, California, Characterization of Ammonia, Total Amine, Organic Sulfur Compound, and Total Non-Methane Organic Compound (TGNMOC) Emissions from Composting Operations*. South Coast Air Quality Management District. November 16, 1996.

[16] ibid

[17] SCAQMD. 1996. *Source Test Report 95-0032/96-0003 Conducted at EKO Systems 8100-100 Chino-Corona Road, Corona, California, 91720, Characterization of Ammonia, Total Amine, Organic Sulfur Compound, and Total Non-Methane Organic Compound (TGNMOC) Emissions from Composting Operations*. South Coast Air Quality Management District. May 16, 1996.

the composting cycle. The reported emissions were for windrows at the site since sampling for curing piles emissions was not performed. Piles at the site were turned one to three times per week and samples were collected after turning had been completed. The estimated facility wide emissions did not include curing pile emissions and were calculated using the average of the three windrow ages[18].

Table 5.2: EKO Systems Average Emissions for 2-day, 20-day, and & 50-Day Piles:

Chemical	Emissions per ton of Compost Mix
Ammonia	3.28 lbs/ton mix
Amines	<0.0003 lbs/ton mix
Total Sulfur Compounds	0.015 lbs/ton mix
TGNMOC	1.70 lbs/ton mix

An average value from the two studies was estimated and used as the source term for the dispersion model. The average was used rather than the default emission factors listed in SCAQMD Rule 1133.2 since

1. The San Joaquin facility composted 50% biosolids and 50% greenwaste;
2. The EKO facility composted manure and biosolids; and
3. The feedstock of the proposed ABT-Haskell facility will be similar to a mixture of the San Joaquin and EKO facilities.

The average values are:

Table 5.3: Average Emissions for San Joaquin and EKO Studies:

Chemical	Emissions per ton of Compost Mix
Ammonia	3.045 lbs/ton mix
Amines	0.09515 lbs/ton mix
Total Sulfur Compounds	0.1175 lbs/ton mix

18 ibid

TGNMOC	2.41 lbs/ton mix

The proposed ABT-Haskell facility is capable of treating 100,000 tons of wet biosolids over the course of a year. The table below details the maximum emissions for 100,000 tons of wet biosolids being composted assuming no emission controls, 80% emission control (minimum requirement to meet SCAQMD Rule 1133), 95% emission control, 99% emission control, and 99.9% emission control (rated emission control for the ABT-Haskell AirLance™ System). These input values were used to derive ground level concentrations of chemicals potentially being emitted from the facility in the dispersion model.

Table 5.4: Annual Potential Emissions For 100,000 Tons of Biosolids:

	Pounds of Emissions Per Year			
Chemical	80% Control	95% Control	99% Control	99.9% Control
Ammonia	60,900	15,225	3,045	304.5
Amines	1,903	475.75	95.15	9.515
Total Sulfur Compounds	2,350	587.5	117.5	11.75
TGNMOC	48,200	1,2050	2,410	241

6 METEOROLOGICAL DATA

The climate in Los Angeles is characterized by moderate temperatures with comfortable humidities and limited precipitation. Temperatures are normally mild, with rare extremes above 100 °F or below freezing. Mean annual precipitation is approximately 14.5 inches, of which, approximately 12.2 inches occur from November through March.

For modeling purposes, the SCAQMD uses 1981 meteorological data (i.e., hourly winds, temperature, atmospheric stability, and mixing heights) from 35 sites in the district. The 1981 meteorological data are used because this data set represents the most complete and comprehensive data set currently compiled. These data are available at the SCAQMD's web site[19] and are in a format that can be directly read by ISCST3. The closest meteorological data station maintained by the SCAQMD was identified from the posted list of sites.

Table 6.1: Meteorological Data

Station ID			UTM (KM)			
SFc	Upper	City Name	E-W	N-S	Long	Lat
54144	99999	BANNING	510.5	3754.5	116:53:11	33:55:58
54149	99999	FONTANA	455.4	3773.9	117:29:01	34:06:24
54161	**99999**	**REDLANDS**	**486.2**	**3769.4**	**117:09:00**	**34:04:00**

Each data file contains preprocessed meteorological data, formatted into columns; one record per hour. The windrose, or visual display of the windpattern measured at Station 54161, is presented in Figure 6.1. The predominant windpattern in the vicinity of the Site is from the west-northwest during the daytime and from the east during the nighttime.

[19] www.aqmd.gov/metdata

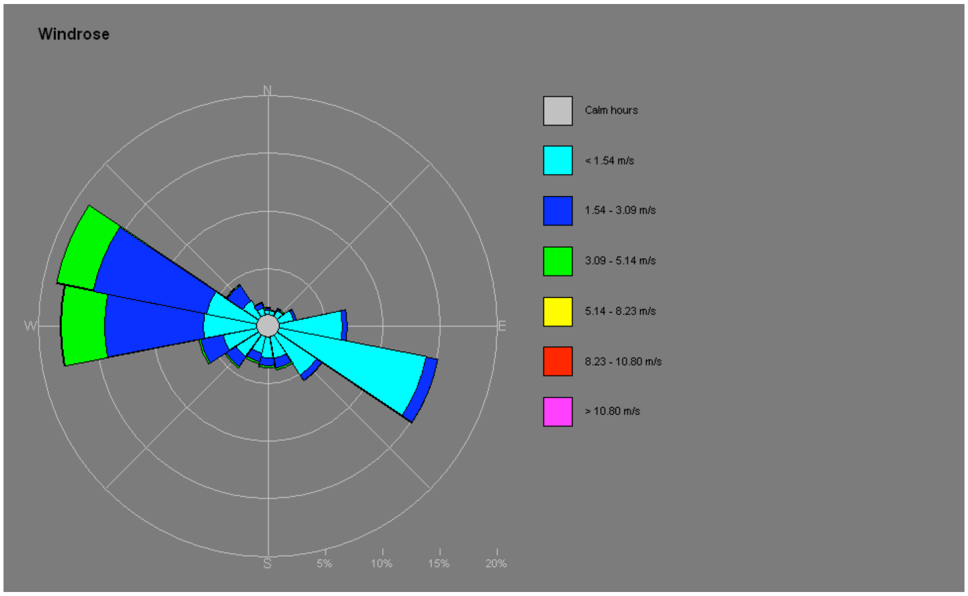

Figure 6.1: Annual Windpattern (Windrose) for Redlands, California

During the winter the predominant wind pattern is dominated by winds from the southeast (counter-current winds from high pressure systems to the west of the Los Angeles Coastal Basin). Frequent rains from December to February dominate the wet season for the Los Angeles Coastal Basin. Stronger winds from the west northwest occur less frequently.

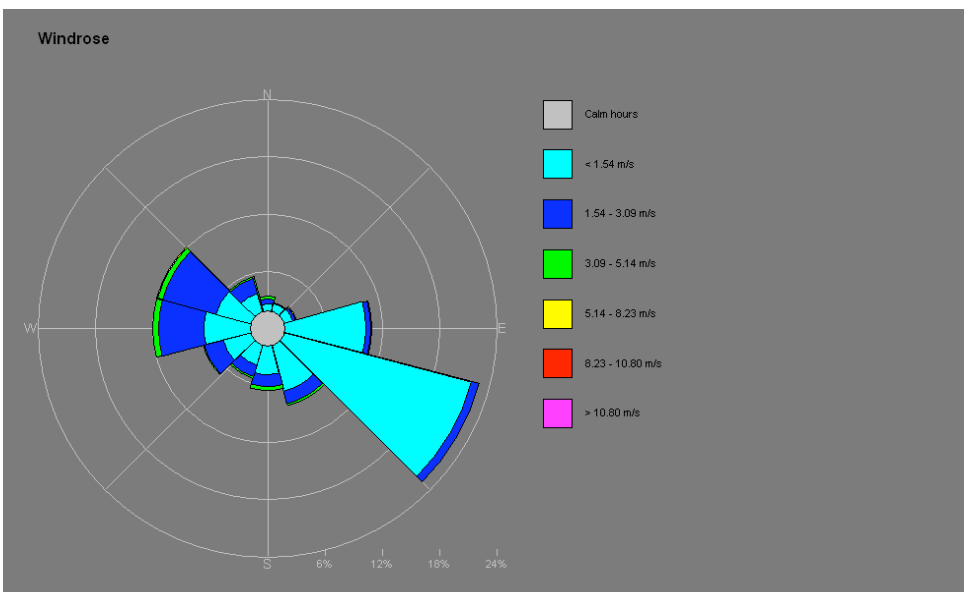

Figure 6.2: Winter Windpattern (Windrose) for Redlands, California

During the spring the predominant wind pattern is dominated by winds from the west-northwest (coastal onshore influence).

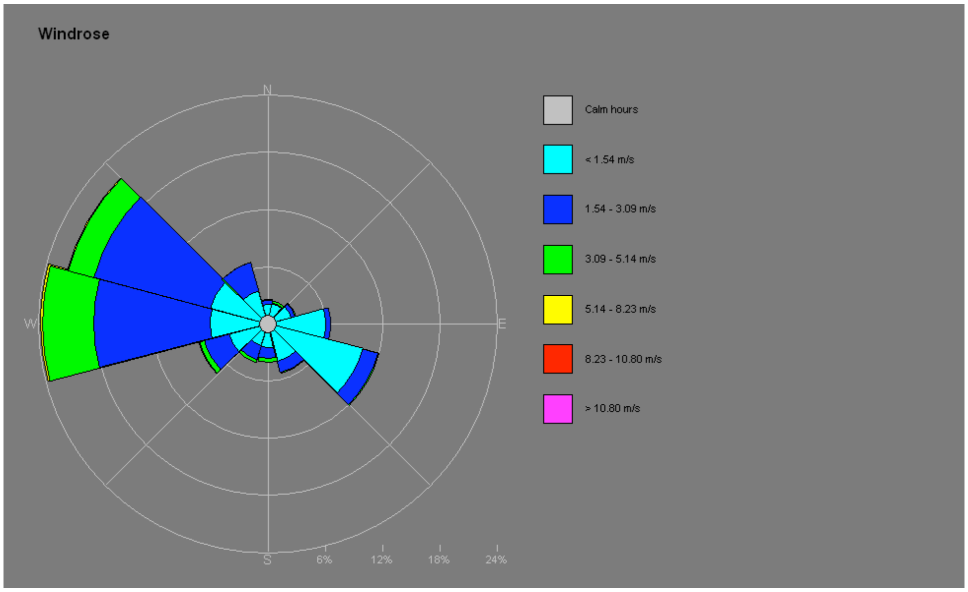

Figure 6.3: Spring Windpattern (Windrose) for Redlands, California

During the summer the predominant wind pattern is dominated by winds from the west-northwest (coastal onshore influence).

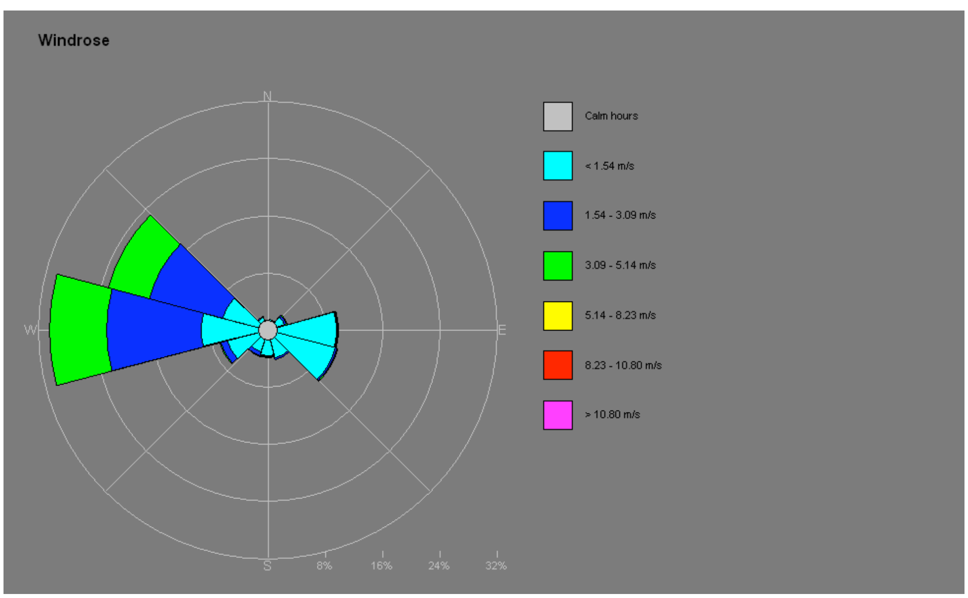

Figure 6.4: Summer Windpattern (Windrose) for Redlands, California

During the fall the predominant wind patterns shift from a strong west-northwest flow to a east-southeasterly flow. This shift highlights the end of the dry season and the start of the winter wet season.

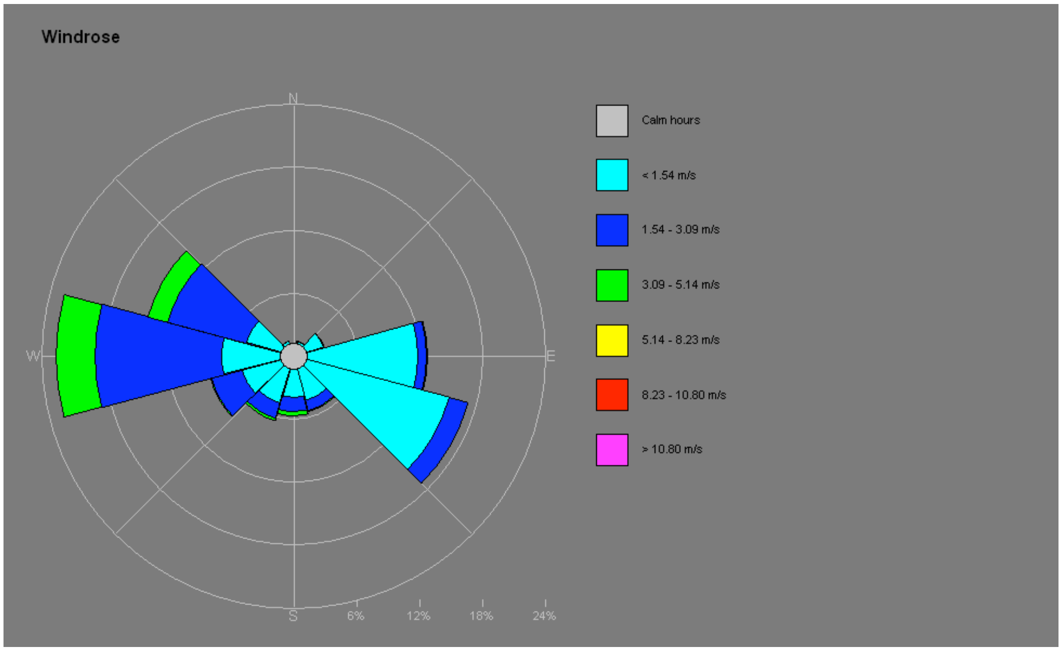

Figure 6.5: Fall Windpattern (Windrose) for Redlands, California

7 ISCST3 MODELING

The Industrial Source Complex-Short Term (ISCST3) model was performed on potential emissions from the ABT-Haskell facility and ground-level concentrations (GLCs) of each compound were calculated for a ½ mile radius of the Site. The model is a steady state Gaussian plume model and is approved by the U.S. EPA for estimating ground level impacts from point and fugitive sources in simple and complex terrain. This model can account for the following: settling and dry deposition of particles; downwash; point, area, line, and volume sources; plume rise as a function of downwind distance; separation of point sources; and limited terrain adjustment. ISCST3 operates in both long-term and short-term modes.

For this study, the dispersion of chemicals was modeled from a point source at the facility. Preliminary designs for the facility show a 54 inch stack from the filtration system exiting at a height of approximately 50 feet above ground surface. The estimated exit velocity for gases from the stack will be approximately 65,000 cubic feet per minute (cfm). Gases were also assumed to be exiting the stack at a temperature of 90 °F. The source terms or concentration of chemicals being emitted from the facility were assumed to be equivalent to the concentrations achieved from 80%, 95%, 99%, and 99.9% control via the previously described scrubber system.

Table 7.1: Annual Potential Tons of Emissions For 100,000 Tons of Biosolids:

			Tons of Emissions Per Year			
Chemical	Tons of Emissions per ton of Compost Mix	Tons of Emissions Without Control	80% Control	95% Control	99% Control	99.9% Control
Ammonia	0.0015225	152	30	7.6	1.52	0.152
Amines	0.000047575	5	1	0.2	0.05	0.005
Total Sulfur Compounds	0.00005875	6	1	0.3	0.06	0.006
TGNMOC	0.001205	121	24	6.0	1.21	0.121

A receptor grid was placed over the system with cells 100 meters by 100 meters. The receptor grid was approximately 3100 meters by 2100 meters in dimension.

Additionally, a fence-line receptor system was set along the property boundary. GLCs were calculated for each of the chemicals, assuming 80%, 95%, 99%, and 99.9% control. The model was run iteratively to determine the maximum 1-hour, 12-hour, and annual average GLCs within the receptor system.

The ISCST3 model output files are presented in Appendix F. Predicted mass GLCs corresponding to the model output values expressed in micrograms per cubic meter (ug/m^3) were derived.

The GLCs were compared to the lowest odor threshold for ammonia as reported by Ruth (1986). Indicator compounds and odor thresholds used in this analysis for amines, sulfur compounds, and TGNMOC are shown in Table 7.2.

Table 7.2: The indicator compounds and the odor threshold

Chemical	Surrogate	Odor Detection Limit
Sulfur	DMDS	0.1 ug/m^3
Amines	TMA	0.8 ug/m^3
Ammonia	NH_3	26.6 ug/m^3
TGNMOC	Phenol	178 ug/m^3

The results of the modeling are presented in Figures 7.1 through 7.49 of the Figure Section.

Sulfur compounds have the lowest odor detection threshold, driving the resulting analysis. While the annual average for the 80% control of sulfur compounds did not exceed the odor threshold on or off the site (Figure 7.10), 1-hour and 12-hour maximums did exceed the odor threshold for receptors on and off-site (Figures 7.2 and 7.6).

For the 95% control scenario of sulfur compounds, the annual average and 12-hour maximum analysis did not exceed the odor threshold for sulfur compounds (Figures 7.11 and 7.7). The 1-hour maximum average did exceed the odor threshold for receptors on and off-site (Figure 7.3).

For the 99% and 99.9% control scenarios, the odor threshold was not exceeded for the annual average, 12-hour maximum, or the 1-hour maximums for receptors on or off-site (Figures 7.4, 7.5, 7.8, 7.9, 7.12, and 7.13).

For amines, ammonia, and TGNMOCs, the analyses show that for all of the control scenarios evaluated (80%, 95%, 99%, and 99.9%) odor thresholds were not exceeded (Figures 7.14 through 7.49).

8 CONCLUSION

The proposed ABT-Haskell facility will be a valuable asset to San Bernardino County in meeting the requirements of AB 939 and will meet the requirements of South Coast Air Quality Management District (SCAQMD) Rule 1133.2.

Dispersion modeling of potential emissions from the proposed facility show that when the system is operational the proposed ABT-Haskell composting facility will have a *de mininus* impact upon the Redlands Community with regard to odor and volatile organic compounds emissions.

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APPENDIX A: SCAQMD RULE 1133.2

APPENDIX B: ODOR DETECTIONS LIMITS RUTH

APPENDIX C: SAN JOAQUIN REPORT

APPENDIX D: EKO REPORT

APPENDIX E: ISCST3 MODEL OUTPUTS

(See attached CD)

FIGURES

Environmental Health Perspectives Volume 114, Number 8, August 2006

Research

Volatile Organic Compounds and Pulmonary Function in the Third National Health and Nutrition Examination Survey, 1988–1994

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Abstract
Background: Volatile organic compounds (VOCs) are present in much higher concentrations indoors, where people spend most of their time, than outdoors and may have adverse health effects. VOCs have been associated with respiratory symptoms, but few studies address objective respiratory end points such as pulmonary function. Blood levels of VOCs may be more indicative of personal exposures than are air concentrations ; no studies have addressed their relationship with respiratory outcomes.

Objective: We examined whether concentrations of 11 VOCs that were commonly identified in blood from a sample of the U.S. population were associated with pulmonary function.

Methods: We used data from 953 adult participants (20–59 years of age) in the Third National Health and Nutrition Examination Survey (1988–1994) who had VOC blood measures as well as pulmonary function measures. Linear regression models were used to evaluate the relationship between 11 VOCs and measures of pulmonary function.

Results: After adjustment for smoking, only 1,4-dichlorobenzene (1,4-DCB) was associated with reduced pulmonary function. Participants in the highest decile of 1,4-DCB concentration had decrements of –153 mL [95% confidence interval (CI) , –297 to –8] in forced expiratory volume in 1 sec and –346 mL/sec (95% CI, –667 to –24) in maximum mid-expiratory flow rate, compared with participants in the lowest decile.

Conclusions: Exposure to 1,4-DCB, a VOC related to the use of air fresheners, toilet bowl deodorants, and mothballs, at levels found in the U.S. general population, may result in reduced pulmonary function. This common exposure may have long-term adverse effects on respiratory health.

Key words: air fresheners, air pollution (indoor) , deodorants, 1, 4-dichlorobenzene, exposure, environmental exposure, FEV_1, lung function, respiratory function tests, VOC. *Environ Health Perspect* 114:1210–1214 (2006) . doi:10.1289/ehp.9019 available via *http://dx.doi.org/* [Online 25 April 2006]

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Introduction

Volatile organic compounds (VOCs) are a diverse group of chemicals emitted as gases from a variety of commonly used products. The general population is exposed to VOCs from cleaning and degreasing agents, pesticides, air fresheners, toilet bowl deodorants, furniture, tobacco smoke, and building materials such as pressed wood products, adhesives, carpeting, paints, and varnishes. Although VOCs are also released into the outdoor air through automotive exhaust and industrial emissions, indoor VOC concentrations are much higher (Wallace et al. 1987, 1991).

Because people spend most of their time indoors, health effects related to VOCs in the residential setting are a concern, particularly with respect to respiratory illness (Diez et al. 2000; Farrow et al. 2003; Fiedler et al. 2005; Harving et al. 1991; Koren et al. 1992; Norback et al. 1995; Pappas et al. 2000; Smedje et al. 1997; Venn et al. 2003; Wieslander et al. 1997). Several studies have shown that elevated air concentrations of VOCs are associated with respiratory symptoms (Diez et al. 2000; Norback et al. 1995; Pappas et al. 2000; Rumchev et al. 2005; Smedje et al. 1997; Wieslander et al. 1997). Studies of VOC exposures and measures of pulmonary function have mostly been small and have used short-term measurements of VOC air concentrations in a single location to characterize exposures, which may not reflect the chronic exposures to these compounds (Fiedler et al. 2005; Harving et al. 1991; Norback et al. 1995; Pappas et al. 2000; Wieslander et al. 1997). Blood concentrations may better reflect chronic exposures to VOCs because they integrate exposures from all sources and can be used to estimate internal dose (Ashley and Prah 1997; Ashley et al. 1994; Sexton et al. 2005a).

A variety of VOCs were measured in a subset of participants in the Third National Health and Nutrition Examination Survey (1988–1994) (NHANES III) to determine background exposure levels for adults in the general U.S. population (Ashley et al. 1994). Because there is a paucity of information about chronic VOC exposure and pulmonary function, we examined VOC blood concentrations in relation to pulmonary function using data from NHANES III (Ashley et al. 1994).

Materials and Methods

Study population. We used data from NHANES III and its component Priority Toxicant Reference Range Study, designed to assess the levels of common pesticides and VOCs in a representative sample of the U.S. adult population. The studies were conducted from 1988 through 1994. Detailed information about NHANES III and the Priority Toxicant Reference Range Study may be found elsewhere [National Center for Health Statistics (NCHS) 1996, 2000]. Briefly, NHANES III is the seventh in a series of periodic surveys conducted by the NCHS of the Centers for Disease Control and Prevention designed to provide national estimates of the health and nutritional status of noninstitutionalized U.S. civilians ≥2 months of age. The Priority Toxicant Reference Range Study included a sample of 1,338 men and women from NHANES III, 20–59 years of age, selected on the basis of age, race, sex, and region of residence. Among these 1,338 participants, 1,018 provided an additional blood sample for measurement of VOCs and completed a questionnaire about exposure to various chemical products.

Pulmonary function. In NHANES III, spirometry was conducted according to the 1987 American Thoracic Society recommendations (NCHS 2001). The National Institute of Occupational Safety and Health (NIOSH) served as the quality control center for the results. Technicians received formal training and satisfactorily completed an NIOSH-approved course on spirometry.

Our analyses included forced expiratory volume at 1 sec (FEV_1; milliliters), forced vital capacity (FVC; milliliters), peak expiratory flow rate (PEFR; milliliters per second), and maximum mid-expiratory flow rate (MMEFR; milliliters per second). We adjusted all models for race/ethnicity group (indicator variables for African American, Mexican American, and other), age (continuous), age squared (continuous), standing height (continuous), body mass index (continuous), and sex, to account for differences in pulmonary function based on these characteristics.

We included participants in analyses if they had at least two successful pulmonary function maneuvers and if their results were coded as reliable and reproducible. A reliable maneuver was a maximal exhalation without cough, excessive hesitation, leak, obstructed mouthpiece, variable effort, or early termination (NCHS 1996). Reproducible maneuvers were recorded for FVC and FEV_1 and were defined as the largest FVC and second largest FVC within 5%, and the largest FEV_1 and second largest FEV_1 within 5%. Of 1,018 participants with VOC measures, 953 met our pulmonary function inclusion criteria.

VOCs. In the Priority Toxicant Reference Range Study, 32 VOCs were measured in blood, using purge and trap gas chromatography/mass spectrometry as previously described (Ashley et al. 1992, 1994). We analyzed the 11 VOCs with median values above the limit of detection [1,1,1-trichloroethane (1,1,1-TCE), 1,4-dichlorobenzene (1,4-DCB), 2-butanone, acetone, benzene, ethylbenzene, *m*,*p*-xylene, *o*-xylene, styrene, tetrachloroethene, toluene]. Of the 953 participants who had a value for at least 1 of 11 VOCs and who had acceptable pulmonary function data, sample sizes varied across VOCs (range, 513–953), because results for some VOCs were not available for all participants (NCHS 2001). Although the reasons for different sample sizes are not given in the NHANES III documentation, it is possible that some blood samples failed to meet acceptability standards or were invalid due to clotting, or that the laboratory experienced problems with instruments or quality control parameters (Sexton et al. 2005a).

Statistical analyses. We used ordinary least-squares regression models to evaluate the association between each VOC and each pulmonary function outcome. For samples with VOC measures below the limit of detection, a value equal to the detection limit divided by the square root of 2 was assigned (NCHS 2000). We used natural log transformations of VOC concentrations to reduce the influence of their skewed distributions on the regression model estimates. We used Wilcoxon rank-sum tests to compare VOC median values between two groups and Kruskal-Wallis tests to compare values among three or more groups. We performed tests for linear trends across deciles using one-way analysis of variance. We conducted all analyses using SAS (version 9.0; SAS Institute Inc., Cary, NC). Weighting is not recommended for analysis of data from the Priority Toxicant Reference Range Study (NCHS 2000).

For descriptive purposes, we first analyzed VOCs in relation to pulmonary function without adjustment for smoking. However, because smoking and environmental tobacco smoke are sources of VOCs and also affect pulmonary function, we then added terms for smoking status (current, quit within the previous 12 months, quit more than 12 months previously, never), number of cigarettes smoked per day (continuous), years smoked (continuous), and serum cotinine level (continuous). Smoking was a confounder for most VOCs.

We then used a change-in-estimate method to evaluate additional variables as confounders for the VOCs still related to pulmonary function after adjustment for smoking (Greenland 1989). Our cutoff criterion was a 10% change in the VOC β-coefficient in relation to pulmonary function. In this manner, we assessed the following potential confounders: socioeconomic status (education, poverty:income ratio, use of food stamps within the previous 12 months), self-reported doctor diagnosis of emphysema, use of fireplace within the previous 12 months or wood or gas stove for heating or cooking, age of the house (construction year before 1946, 1946–1973, 1974 to present), presence of furred pets at home, and occupational exposure. Occupational exposure (yes, no) was indicated by a variable denoting occupations associated with chronic obstructive pulmonary disease (COPD) in this population (Hnizdo et al. 2002). The only factor that met the criterion for confounding was self-reported doctor diagnosis of emphysema, and this was included in the final models. We repeated analyses excluding people with self-reported doctor diagnosis of asthma, and the results were not changed appreciably.

Results

Characteristics of the study population are shown in Table 1. The mean age was 36.6 years (range, 20–59), 43.1% were female, and 26.3% were current smokers.

Table 2 shows distributions of the 11 VOCs with median values above the limit of detection. As expected, acetone was present in much higher concentrations than other VOCs because it is produced endogenously. Men had significantly higher measured values for most VOCs (Wilcoxon rank-sum tests, $p < 0.05$), except for 1,1,1-TCE, 1,4-DCB, and tetrachloroethene (TCE). As has been reported previously for this population (Churchill et al. 2001), Mexican Americans had lower concentrations of benzene, ethylbenzene, styrene, TCE, and toluene and significantly higher levels of *m*,*p*-xylene than did other ethnic groups. For 1,4-DCB, non-Hispanic whites had the lowest and African Americans the highest concentrations.

In the models unadjusted for smoking, reductions in at least one pulmonary function outcome were statistically significant for 1,4-DCB, benzene, ethylbenzene, styrene, and toluene (data not shown). However, when these models were adjusted for smoking variables, only 1,4-DCB remained statistically significantly associated with reduced pulmonary function. For example, after adjustment for smoking, VOC β-coefficients for FEV_1 changed from –72 mL ($p < 0.0001$) to –1 mL ($p = 0.95$) for benzene, from –51 mL ($p = 0.03$) to 15 mL ($p = 0.57$) for ethylbenzene, from –61 mL ($p = 0.01$) to 42 mL ($p = 0.19$) for styrene, and from –69 mL ($p < 0.01$) to 16 mL ($p = 0.60$) for toluene, whereas the β-coefficient for 1,4-DCB remained unchanged (–24 mL, $p = 0.04$).

Because only 1,4-DCB maintained its association with pulmonary function in the presence of smoking, further analyses were limited to this VOC. The exposure distribution of 1,4-DCB differed by race/ethnicity group (Kruskal-Wallis test, $p < 0.0001$), with African Americans having the highest exposures (Table 3).

Among all participants, 1,4-DCB was inversely related to all four pulmonary function measures but was statistically significant only for FEV_1 and MMEFR (Table 4). Power is limited for sex-specific analyses; however, higher 1,4-DCB was related to lower levels of each pulmonary function measure in both men and women. Likewise, 1,4-DCB was inversely associated with all four measures within each of the race groupings, although numbers become unstable. Numbers are further reduced within the six race/sex groups, but 1,4-DCB was inversely related to at least one of the four pulmonary function measures in each of the six subgroups. The results were strongest and statistically significant for non-Hispanic white females (FEV_1, β = –266, $p = 0.02$) and African-American males (FEV_1, β = –282, $p = 0.01$), although we did not find significant evidence of effect modification by race/sex combinations (multiple partial *F*-test, $p > 0.10$ for all pulmonary function outcomes).

Higher levels of 1,4-DCB were related to reduced pulmonary function in never-smokers as well as smokers (Table 4). Results for never-smokers were similar when we defined nonsmokers in a more stringent manner as having serum cotinine < 0.62 ng/mL, the 75th percentile among nonsmokers ($n = 299$; data not shown).

To further examine the relationship between 1,4-DCB and pulmonary function, we conducted additional analyses using urinary concentrations of 2,5-dichlorophenol (2,5-DCP), the major metabolite of 1,4-DCB (Hissink et al. 1997). 2,5-DCP was one of 12

Table 1.

Table 1. Selected characteristics of participants in NHANES III Priority Toxicant Reference Range Study (1988–1994).

	Males (n = 542)	Females (n = 411)	Total[a] (n = 953)
Race/ethnicity (%)			
Non-Hispanic white	39.9	38.2	39.1
African American	32.3	31.1	31.8
Mexican American	25.3	26.3	25.7
Other	2.6	4.4	3.4
Smoking status (%)			
Current smokers	29.5	22.1	26.3
Former smokers[b]	1.3	1.2	1.3
Former smokers[c]	15.3	9.3	12.7
Never smokers	53.9	67.4	59.7
Potential confounders (%)			
Diagnosed asthma[d]	7.0	9.0	7.9
Diagnosed emphysema[d]	1.1	0.7	0.9
Presence of furred pets	34.3	35.8	34.9
Occupation with COPD risk	31.5	12.2	22.3
Pulmonary function measures (mean ± SD)			
FEV_1 (mL)	3,675 ± 732	2,987 ± 544	3,440 ± 825
FVC (mL)	4,858 ± 826	3,516 ± 612	4,279 ± 996
PEFR (mL/sec)	9,374 ± 1,834	6,731 ± 1,292	8,234 ± 2,085
MMEFR (mL/sec)	3,813 ± 1,344	3,025 ± 1,016	3,472 ± 1,275
Age (years) (mean ± range)	36.9 ± 20–59	36.2 ± 20–59	36.6 ± 20–59

[a]Subjects in this table were included in at least one analysis of VOC blood concentration and pulmonary function. [b]Former smokers who quit smoking within the previous 12 months. [c]Former smokers who quit smoking > 12 months previously. [d]Self-reported doctor's diagnosis of asthma or emphysema.

Table 2.

Table 2. Values of selected VOCs[a] (μg/L) measured in participants in NHANES III Priority Toxicant Reference Range Study, 1988–1994, limited to participants with pulmonary function data.

		Total		Males				Females			
VOC	LOD	No.[b]	< LOD[c]	No.	Median	10th	90th	No.	Median	10th	90th
1,1,1-TCE	0.09	513	122	292	0.14	0.06	0.54	221	0.13	0.06	0.41
1,4-DCB	0.07	854	38	491	0.33	0.11	3.89	363	0.30	0.10	4.83
2-Butanone	0.50	908	0	515	5.58	2.41	13.72	393	5.36	2.26	11.28
Acetone	200	852	0	479	1,945	801	7,187	373	1,788	769	6,109
Benzene	0.03	743	113	421	0.07	0.02	0.42	322	0.06	0.02	0.26
Ethylbenzene	0.02	570	33	325	0.07	0.03	0.22	245	0.05	0.02	0.16
m,p-Xylene	0.03	953	362	542	0.13	0.02	0.47	411	0.11	0.02	0.34
o-Xylene	0.04	593	24	343	0.11	0.06	0.21	250	0.10	0.06	0.17
Styrene	0.02	589	74	336	0.05	0.01	0.16	253	0.04	0.01	0.10
Tetrachloroethene	0.03	539	133	306	0.07	0.02	0.38	233	0.06	0.02	0.32
Toluene	0.09	540	4	308	0.33	0.14	1.32	232	0.25	0.13	0.88

LOD, limit of detection. 10th and 90th are percentiles.
[a]Compounds were selected if median values were above the limit of detection. VOCs not meeting inclusion criterion: 1,1,2,2-tetrachloroethane, 1,1,2-TCE, 1,1-dichloroethane, 1,1-dichloroethene, 1,2-DCB, 1,2-dichloroethane, 1,2-dichloropropane, 1,3-DCB, bromodichloromethane, bromoform, carbon tetrachloride, chlorobenzene, chloroform, cis-1,2-dichloroethene, dibromochloromethane, dibromomethane, methylene chloride, trans-1,2-dichloroethene, and trichloroethene. [b]Number of available samples for each VOC. Not all VOCs were measured in every individual, resulting in different sample sizes. [c]Number of participants with samples below the limit of detection.

Table 3.

Table 3. Distribution of 1,4-DCB by sex and race/ethnicity group in NHANES III Priority Toxicant Reference Range Study, 1988–1994.

	Males					Females				
	No.	Median	Range	10th	90th	No.	Median	Range	10th	90th
Non-Hispanic Whites	200	0.22	0.05–18.98	0.09	1.75	140	0.20	0.05–20.47	0.08	1.66
African Americans	157	0.56	0.06–51.24	0.15	6.56	111	0.52	0.06–46.46	0.16	6.67
Mexican Americans	132	0.34	0.05–51.89	0.10	5.64	98	0.29	0.05–28.52	0.09	7.26

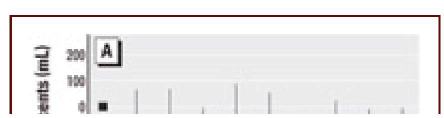
10th and 90th are percentiles.

Table 4.

[illegible]

	No.	FEV_1	FVC	PEFR	MMEFR
All participants	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Males	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Females	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Whites	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
African Americans	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mexican Americans	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
White males	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
White females	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
African American males	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
African American females	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mexican American males	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mexican American females	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ever smokers	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Never smokers	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]



pesticide metabolites measured in the urine of NHANES III participants, using capillary gas chromatography and tandem mass spectrometry (Hill et al. 1995b). Although 2,5-DCP measurements were available only on 534 of the 846 subjects included in the analysis of 1,4-DCB, the β-coefficients for both compounds were inversely related to all pulmonary function measures, and the result for FEV_1 was more statistically precise. For example, the expected change in FEV_1 with each increase in exposure from the 10th to 90th percentile (3.76 μg/L for 1,4-DCB and 4.67 μg/L for 2,5-DCP) was –96 mL (p = 0.03) for 1,4-DCB and –134 mL (p = 0.02) for 2,5-DCP.

To facilitate interpretation of the association between 1,4-DCB and pulmonary function that we observed in these data using logarithmic transformation, we categorized nontransformed values of 1,4-DCB into deciles. Figure 1 shows the changes in FEV_1 (milliliters) and MMEFR (milliliters per second) for each decile of 1,4-DCB exposure, compared with participants in the lowest decile. Tests for linear trend across deciles were statistically significant (FEV_1, p = 0.02; MMEFR, p = 0.02). Subjects in the highest decile of exposure had FEV_1 decrements of –153 mL [95% confidence interval (CI), –297 to –8] and MMEFR decrements of –346 mL/sec (95% CI, –667 to –24), compared with participants in the lowest decile.

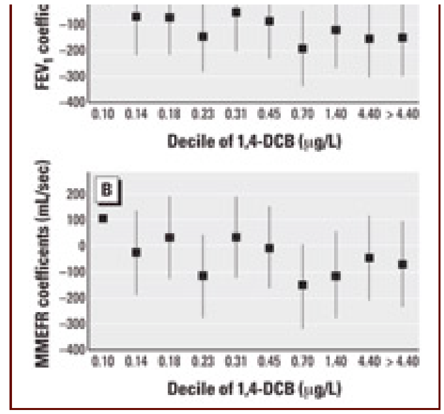


Figure 1. Changes in FEV_1 (*A*) and MMEFR (*B*) (with 95% CIs) for each decile of 1,4-DCB

Discussion

We examined the relationship between blood concentrations of 11 VOCs with median values above the limit of detection and pulmonary function outcomes in participants of NHANES III and found that 1,4-DCB was the only VOC associated with reduced pulmonary function after adjustment for smoking. Participants in the highest decile of 1,4-DCB concentration had FEV_1 and MMEFR decrements of –153 mL (95% CI, –297 to –8) and –346 mL/sec (95% CI, –667 to –24), respectively, compared with participants in the lowest decile. This compares with a 100-mL deficit in FEV_1 for the highest tertile of serum cotinine in nonsmoking females in the NHANES III population (Eisner 2002).

Because we conducted separate analyses for 11 different VOCs, it is possible that the statistical significance of the inverse association between 1,4-DCB and pulmonary function occurred by chance. However, this seems unlikely given the consistent results across subgroup analyses. Furthermore, an analysis of pulmonary function and 2,5-DCP, the urinary metabolite of 1,4-DCB, resulted in similar associations, with the result for FEV_1 reaching statistical significance, despite the smaller sample size.

It is possible that 1,4-DCB blood concentrations may reflect exposure better than do blood concentrations of other VOCs, because air and blood concentrations are better correlated for 1,4-DCB (Sexton et al. 2005a). In the School Health Initiative: Environment, Learning, Disease (SHIELD) study, 2-day integrated personal air samples of indoor VOCs were taken immediately before taking VOC blood measurements from 143 children in Minneapolis (Sexton et al. 2005a). Personal air samples and VOC blood measurements were taken four times over 2 years. Among the VOCs measured, only 1,4-DCB had a high correlation between air and blood concentrations (R^2 = 0.79). Except for acetone and 2-butanone, that study measured the same VOCs we included in our analyses.

Although VOCs generally do not persist in the blood after termination of acute exposure (Ashley and Prah 1997), after frequent prolonged exposures, blood concentrations can reflect chronic exposures (Ashley and Prah 1997; Ashley et al. 1994; Sexton et al. 2005a, 2005b). For example, examination of the uptake and elimination of some VOCs has suggested that bioaccumulation may occur in multiple storage sites in the human body (Ashley and Prah 1997). In the SHIELD study, the between-child variability of 1,4-DCB blood concentrations greatly exceeded the within-child variability (ratio = 434), suggesting that one blood measurement of 1,4-DCB is a good indication of an individual's blood concentration over time. In contrast, other VOCs had much lower ratios of between- and within-child variability; for example, the next highest were for TCE (ratio = 2), ethylbenzene (ratio ~ 1), and 1,1,1-TCE (ratio ~ 1). The high ratio of between- to within-child variability for 1,4-DCB was not seen in the younger children of the Developmental Research on Attention and Memory Skills (DREAMS) study, but far fewer children had more than one blood sample to estimate the ratio of within- to between-child variability (e.g., 126 in the SHIELD study compared with 22 in the DREAMS study) (Sexton et al. 2005b).

Apart from the findings in the SHIELD study (Sexton et al. 2005a), little is known about the relationship between personal 1,4-DCB exposures and blood concentrations. Based on data from a graph of this relationship in children (Sexton et al. 2005a), we estimate that a 1,4-DCB blood concentration of 10 μg/L may correspond to personal exposures of 102 $\mu g/m^3$ or greater, which is close to the proposed chronic duration minimal risk limit (120 $\mu g/m^3$) [Agency for Toxic Substances and Disease Registry (ATSDR) 2004]. Blood levels of 1,4-DCB were higher in children from the SHIELD study than in the NHANES III adults we studied. For example, the 95th percentile was 11.03 μg/L for NHANES III and 27.00 μg/L for the SHIELD study. If 1,4-DCB air concentrations can be extrapolated from blood concentrations, it is possible that the highest blood concentrations of 1,4-DCB in NHANES III represent exposures to air concentrations greater than the proposed chronic duration minimal risk limit.

People who use air fresheners, toilet bowl deodorants, and mothballs have potential for high exposure to 1,4-DCB because it is an important component of these products (ATSDR 2004; Churchill et al. 2001). However, exposure also occurs in the absence of these products as the compound is common in indoor environments. For example, the U.S. Environmental Protection Agency's Total Exposure Assessment Methodology (TEAM) study in 1987 found 1,4-DCB in the air of 80% of the homes surveyed (Wallace et al. 1987), although only one-third of the homes used products containing 1,4-DCB (Wallace 1991). The finding that 96% of the NHANES III subset had detectable 1,4-DCB blood concentrations (Hill et al. 1995a) is further evidence that exposure is common (Sampson et al. 1994).

Although 1,4-DCB is common in indoor environments, little is known about its effects on human health. Hepatic, dermatologic, and respiratory effects have been reported with acute exposures, but these case reports lack clear information about exposure levels (ATSDR 2004; National Institutes of Health 2005). Data from a single occupational study of 58 men (Hollingsworth et al. 1956) were used in conjunction with animal studies to derive acute and chronic exposure levels in the air considered to pose the minimal risk to humans (ATSDR 2004). Because these limits are derived mostly from animal studies, uncertainty factors are used for extrapolation to humans. The minimal risk limits for human exposure to 1,4-DCB are 2 ppm (12 mg/m^3) for acute duration (≤ 24 hr), 0.1 ppm (0.6 mg/m^3) for intermediate duration (> 14 days but < 1 year), and 0.02 ppm (0.12 mg/m^3) for chronic duration (up to a lifetime) (ATSDR 2004).

Among the studies that have measured 1,4-DCB air or blood concentrations (Delfino et al. 2003; Hollingsworth et al. 1956; Rumchev et al. 2005; Sexton et al. 2005a, 2005b; Wallace et al. 1987, 1991), only three measured health outcomes (Delfino et al. 2003; Hollingsworth et al. 1956; Rumchev et al. 2005). Of these, only two measured respiratory outcomes and included only children. In one study, children 6 months to 3 years of age (n = 88) had higher odds of asthma with increasing indoor air concentrations of 1,4-DCB (Rumchev et al. 2005). In a panel study of 22 asthmatic children 10–16 years of age, respiratory symptoms were associated with outdoor air concentrations of total VOCs but not with 1,4-DCB alone (Delfino et al. 2003). Children in this study measured morning and evening peak flow; no relationship with any VOC was observed. No other pulmonary measures were tested. As expected, outdoor air concentrations of 1,4-DCB were low (0.3–3.0 $\mu g/m^3$).

Indoor air concentrations of 1,4-DCB are significantly greater than outdoor air concentrations (Wallace et al. 1987). For example, the TEAM study measured mean personal exposures of 21 $\mu g/m^3$ and indoor concentrations of 30 $\mu g/m^3$, compared with outdoor concentrations of 2.0 $\mu g/m^3$ (Wallace et al. 1987). According to other measures, levels in some homes and public restrooms may reach almost 1.64 mg/m^3 (ATSDR 2004), which is greater than the minimal risk limit for chronic exposure.

The chronic duration minimal risk limit is based on observed eosinophilic changes in the olfactory epithelium of rats; no information was available on effects of exposure on pulmonary function (ATSDR 2004). Although reductions in pulmonary function can be transient and do not necessarily reflect permanent adverse health effects (ATS 2000), they generally precede permanent effects. Thus, chronic reduction in FEV_1 is a sentinel event for adverse health effects from inhaled exposures, such as air pollution (ATS 2000). In particular, FEV_1 has been identified as a risk factor in cardiovascular disease, stroke, and lung cancer, as well as an important predictor of all-cause mortality (Hole et al. 1996).

It is probable that most exposures to 1,4-DCB are chronic, rather than acute and sporadic, because 1,4-DCB is a component of household products used for prolonged periods. For example, air fresheners, toilet bowl deodorants, and mothballs are used until their emissions cease, and then they are replaced. Staff interviewers in the SHIELD study, where blood concentrations of 1,4-DCB were high, noted that many children's homes had pervasive scents of air fresheners (Sexton et al. 2005a). In NHANES III, 32.1% of the participants in the VOC study reported recent use of air fresheners or room deodorizers. Fewer participants reported recent use of toilet bowl deodorants (8.7%), although their use was associated with a 2-fold increase in odds of having high 1,4-DCB blood levels (Churchill et al. 2001).

Because NHANES III is a cross-sectional study, measurements of exposure and outcome were made at the same time, and it is not possible to determine if 1,4-DCB exposure preceded pulmonary function decline. A longitudinal study measuring pulmonary function and exposure to 1,4-DCB at various time points would be necessary to evaluate the temporality of this relationship. Although it is possible that people who are exposed to toilet bowl or air fresheners and other room deodorizers might also be exposed to cleaning products that impair pulmonary function, we had no data to address this.

The inverse association between 1,4-DCB concentration and pulmonary function may have been affected by unmeasured confounders. We assessed the influence of other factors that may be related to pulmonary function and to 1,4-DCB exposure, such as type of heating, use of wood fires, age of house, presence of furred pets, occupation, socioeconomic status, presence of environmental tobacco smoke, smoking history, and diagnosis of asthma or emphysema. Only emphysema confounded the relationship between 1,4-DCB and pulmonary function deficits. The ability to carefully adjust for smoking with several variables, including the objective measure of environmental tobacco smoke exposure, serum cotinine, was a considerable strength of our analyses.

The size and diversity of this NHANES III sample make it possible to examine the relationships between VOCs and pulmonary function in more detail than has been possible in smaller studies. Our findings suggest that 1,4-DCB exposure at levels found in the U.S. general population may result in decreases in pulmonary function. Larger and longitudinal studies would be necessary to properly evaluate the effects on respiratory symptoms and disease.

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The California Clean Air Act requires air districts responsible for air basins designated as having "serious," "severe," or "extreme" ozone air pollution to have ozone attainment plans, which assure that reasonably available control technology (RACT) is in use at major sources and on source categories subject to control technology guidelines (CAA Sections 182(b)(2), 182(f)). Attainment plans should include the application of best available control technology (BACT) to existing major stationary sources (Federal Register 8/18/94). Ozone attainment plans also should provide for best available retrofit control technology (BARCT) for existing permitted sources (California Health & Safety Code (CH&SC) Section 40919(a)(3)). Ozone attainment plans should include "all feasible control measures" (CH&SC Section 40914(a)(2)).