

## **New Landfill Gas Treatment Technology Dramatically Lowers Energy Production Costs**

P. Tower and J. Wetzel, Applied Filter Technology, Inc., Snohomish, WA, X. Lombard, Verdesis, Brussels, Belgium

### **Abstract**

Landfill gas is most often highly contaminated with numerous volatile chemicals, some of which are harmful to power generation equipment or emission catalysts. This high concentration of volatile chemicals complicates the treatment of this gas. Traditional media-based treatment methods fall short in being able to produce the purity of gas at the acceptable cost required by most power generation projects. These media-based treatment systems for high landfill gas flow are large in size and require periodic maintenance to perform to even minimal gas quality standards. In addition, they produce a large volume of spent media that must be disposed, usually in the same landfill or in another landfill.

Introduced in 2004, a new continuously self-regenerated landfill gas treatment technology offers a smaller footprint, lower operating costs, and better gas quality than competitive methods. This new technology, called the SWOP™ Process was installed at a landfill near Paris, France in early 2005 to treat between 7,500 and 8,200 Nm<sup>3</sup>/h (4,400 to 4,800 SCFM). This gas is used to fire a 10 MWe turbine. Two other 2005 installations of the SWOP™ Process are at landfill sites in South Carolina, US; one to protect a turbine generating 5 MWe and one to protect 5 x 1 MWe each reciprocating generator engines. Each of these units handles a nominal 2,500 SCFM of landfill gas. The SWOP™ Processes at the landfill near Paris and at the South Carolina landfills remove siloxanes and other organosilicon species as well as other VOCs from the landfill gas to prevent damage to the power generation equipment. In each case, the SWOP™ Systems provided superior technical and economic advantages over other gas treatment processes. Nine months of operation for the world's first SWOP™ System has demonstrated a VOC reduction by a factor of 10 and "polishing" media reduction by a factor of 5. A huge benefit is very low consumption of power by the process. Full automation of the process is the key for day to day trouble-free operation.

The SWOP™ Process utilizes some of the purified landfill gas (around 0.5% to 1.5%) for continuous self-regeneration. VOCs and siloxanes are removed and concentrated into a small gas stream that is sent to an enclosed ground flare for destruction, thus eliminating this contamination.

The paper focuses on the factors used to select the SWOP™ Process over other technologies for the site near Paris and the two sites in South Carolina, the capital and installation costs, the operating costs and the quality of the gas produced. Challenges encountered during the installation and startup are also discussed. The paper concludes by comparing the SWOP™ Process to other technologies and details the very positive cost-saving benefits.

### **Background**

Traditional treatment systems for the removal of siloxanes and VOCs have been found to have several drawbacks. First, they are often expensive to operate. Second, they do not eliminate much, if any of the VOC contamination. Third, and most important, they often do not remove all of the organosilicons. Some organosilicons are not siloxanes and are much more difficult to remove. For example, Verdesis has found that even the best activated carbon allowed an almost constant breakthrough of 1 to 5 mg/m<sup>3</sup> of siloxanes. Fourth, with deep chilling and

desiccant-based treatment systems, the siloxanes and VOCs that are removed from the system are either vented off to atmosphere or condensed and disposed of on site as a liquid waste stream.

Among the types of treatment systems used for landfill gas are the SAG™ carbonaceous adsorbent media-based (approximately 70 systems installed worldwide), deep chilling (exact number of installed systems is unknown, but estimate to be less than 5), and regenerable desiccant media-based systems (2 known “beta” installations on LFG). The SAG™ systems generate spent media that must be disposed. Although this technology is effective in removing both siloxanes to non-detectable levels and VOCs, it is best suited for gas streams with a low to moderate total VOC burden, which dictates media replacement intervals. In landfill gas, the VOC content of the gas is the overriding factor that determines the equipment design and operating costs.

The deep chilling process (down to -10 degrees F. or -23.3 degrees C.) is offered with claims of removing greater than 95% of all siloxanes and VOCs. It produces a liquid waste stream of condensed VOCs that must be disposed. The SAG™ Process is normally preceded by a gas conditioning step to reduce the moisture level in the gas so that it does not interfere with siloxane and VOC removal. The deep chilling process also reduces the moisture level in the gas prior to VOC removal. The regenerable desiccant system is not normally preceded by a gas conditioning package except for a coalescing filter, and removes moisture from the gas until it becomes saturated. Desiccant media regeneration is based on siloxane breakthrough rather than moisture breakthrough.

The regenerable desiccant system is claimed to remove greater than 95% of the siloxanes. It is unknown if the desiccant system removes the VOCs and to what extent. It is believed that the VOCs are removed for a short period of time after start-up and after each regeneration cycle, after which they break through (perhaps even before the breakthrough of water). The regeneration cycle on the pilot sites is reported to be approximately once a week.

It should be pointed out that both the deep chilling system and the regenerable desiccant system are technologies that were originally designed to predictably remove moisture from air or gas. Thus, these technologies are based on engineering principles and concepts that are widely accepted for removal of moisture. The ability of these systems to remove siloxanes and VOCs, however, is presently undocumented in publicly accessible published literature, although information is expected to be presented in the near future on the regenerable desiccant system.

## The Problem

The use of biogas for power generation or for other combustion uses presents several problems, only one of which—silicon dioxide and silicate production—receives real attention. A second problem that receives a fair amount of attention is hydrogen sulfide in the gas. A problem that receives little attention, but that has looming importance is the emission of VOCs that are contained in the landfill gas. All of the previously described gas treatment technologies remove at least some of the VOCs in the landfill gas. The regenerable desiccant system vents these to the atmosphere upon regeneration of the media or, in the case of the deep chilling process, they are condensed to a liquid and conveyed back into the landfill. In addition, both processes vent some methane to the atmosphere through the purging and condensing operations. Some of the VOCs in landfill gas are considered to be damaging to the ozone layer, such as the chlorofluorocarbons. Other VOCs, including the halogenated species, are damaging to emission catalysts. The methane is considered a “greenhouse gas” and thus its scrutiny has become more profound in recent years.

## Introduction

The landfill near Paris, France is one of the largest landfills in France. By the year 2010, 20% of the energy used in France is to come from renewable or "green" sources. Thus, the impetus is on the owner of the landfill to generate power.

Verdesis, a Belgian company, has contracted with the landfill owner to provide treatment equipment to remove organosilicons and VOCs from the landfill gas. This landfill has 10,000 SCFM of landfill gas available. Approximately half of the biogas is used to generate 10 MWe by a steam turbine with an overall efficiency around 28%. The balance of the landfill gas is used to fire a 10 MWe turbine that was commissioned in April of 2005. A combined cycle power generation system is planned to be started by the end of the year 2006. This will be the largest power generation unit on a landfill in Europe at 16MWe.

In order to meet the very stringent organosilicon specification of the turbine manufacturer (<50 ppbv), the client sought to use activated carbon with off-site regeneration of the media. Due to the very high VOC level of the gas and large amount of media that would require regeneration, this was not practical economically, nor had it been proven to effectively remove lower molecular weight organosilicons, like trimethylsilanol. From the beginning, the landfill gas treatment has been considered as a key issue to minimize the maintenance cost and to mitigate the technical risks associated with maintenance and per cent time on-line.

### Biogas analysis

Landfill gas characteristics:

Methane	46% to 48%	
Carbon Dioxide	36% to 38%	
Nitrogen	10% to 12%	
Oxygen	1.5% to 1.8%	
Water vapor	0.4% to 0.6%	
Pressure	150 to 200 Millibars (2.2 to 2.9 psig)	
Total V.O.C.	<>2,320mg/m <sup>3</sup> or 624 ppmv	(280,000 lb/year)
Total organosilicons	<>20 mg/m <sup>3</sup> or 3.17 ppmv	(2,400 lb/year)
Hydrogen Sulfide (H <sub>2</sub> S)	<>300mg/m <sup>3</sup> or 200 ppmv	
Nominal flow	<>7,500 Nm <sup>3</sup> h or 4,400 SCFM	
Operating hours yearly	> 8000 hours	

(see Appendix A for landfill gas VOC details)

### The Problem

It has been well documented by Tower and others (1,3,4,5,6,9,10) that the presence of organosilicon compounds in landfill gas (and digester gas as well) is detrimental to the operation of power generation equipment that burns it as fuel. In the combustion process, these organosilicons become silicon dioxide, a substance that coats and abrades hot and moving parts. This landfill gas, when combusted untreated, will produce approximately 3,600 pounds (1,633 kg) of silicon dioxide (SiO<sub>2</sub>) per year. During the treatment of landfill gas, most

of the VOCs have to be removed in order to remove the organosilicons. For this landfill, this means the removal of around 280,000 pounds or 140 tons (127.3 metric tons) of VOCs.

It is important to note that not all of the organosilicons are siloxanes. Two of the species encountered in this landfill gas are trimethylsilanol, a silicon-containing alcohol, and tetramethylsilane, an industrial chemical. These organosilicons compounds are very difficult to remove. The table below shows the breakdown of the organosilicons species:

#### Organosilicon species in landfill near Paris, France

Species	mg/m <sup>3</sup>	parts per billion, volume
Decamethylcyclopentasiloxane (D5)	2.2	133
Octamethylcyclotetrasiloxane (D4)	5.9	446
Hexamethylcyclotrisiloxane (D3)	1.5	151
Octamethyltrisiloxane (MDM or L3)	.062	5.9
Hexamethyldisiloxane (MM or L2)	1.5	207
Trimethylsilanol Si(CH <sub>3</sub> ) <sub>3</sub> OH	8.9	2,200
Tetramethylsilane Si(CH <sub>3</sub> ) <sub>4</sub>	0.076	19.3
Totals	20.14	3,162.2

Organosilicon content is equivalent to 0.35 to 0.37 ug/BTU. Target is < 0.005 ug/BTU

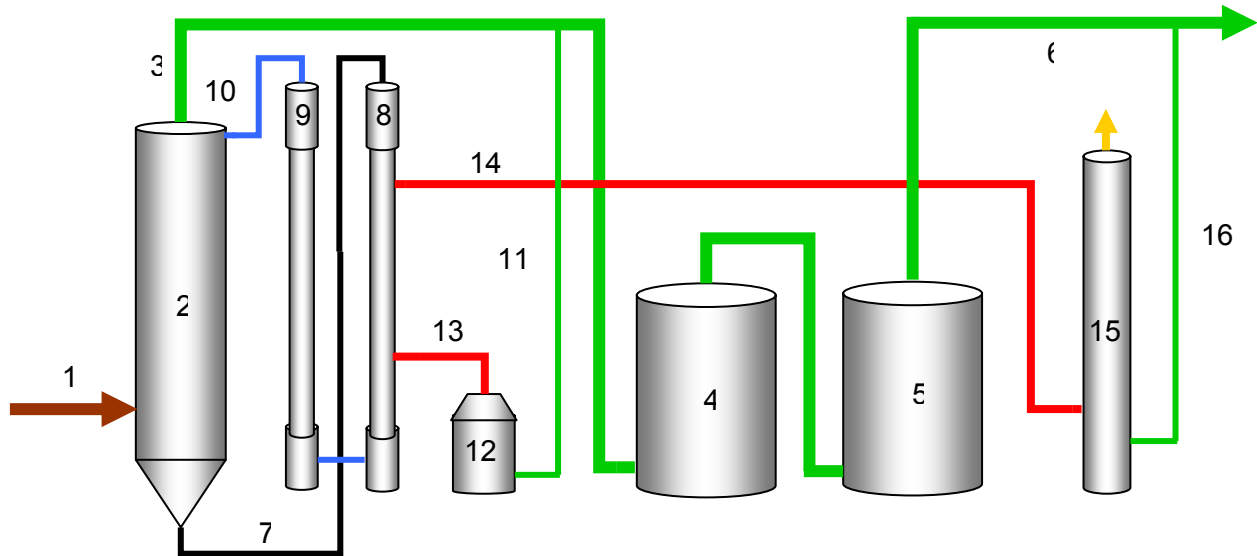
#### The Solution

In the evaluation of treatment technologies, the client wished to not only remove the siloxanes, organosilicons and VOCs, but also to destroy them so they would not be emitted to the atmosphere or become a future environmental liability. For example, putting them back into the landfill would continually increase their concentration in the landfill gas, making their removal more and more difficult. The technologies considered were the AFT SWOP™ Process, Activated Carbon, and deep chilling. Deep chilling was eliminated from consideration early in the project because it does not eliminate the VOCs after they are removed from the landfill gas. Further, deep chilling technology has not been demonstrated to effectively remove all of the organosilicons from the biogas. Activated carbon has also not been demonstrated to remove all of the organosilicons from landfill gas. At one of Verdesis's sites at Biffa, activated carbon did not remove the trimethylsilanol. (A SAG™ system was installed at this site and it has been documented to remove all of the trimethylsilanol to non-detectable levels on a continuous basis). Thus it was decided to install a SWOP™ system followed by a SAG™ System to assure that there are no organosilicons in the treated landfill gas.

Based on its past experience with activated carbon and SAG™ media, Verdesis calculated that they would use 1.2 million pounds per year of activated carbon and about 840,000 pounds per year of SAG™ media to reduce the organosilicons to the required level (< 0.05 mg/m<sup>3</sup>) in the treated landfill gas. This simply was not economical and it was not convenient to remove and install this much media—around 23,000 to 25,000 pounds per week for the activated carbon. With the regenerable SWOP™ Process ahead of the SAG™ Process, the VOC reduction attainable is 90%. The media change out rate was estimated to be around one fifth of the rate without it..

## The SWOP™ Process

There are five separate process operations comprising the SWOP™ Process. The first of these is the process whereby the biogas contaminants are concentrated onto regenerable media in the Concentrator vessel. The second process is the pneumatic conveyance of the media from the Concentrator vessel to the stripper vessel and back to the Concentrator vessel. The third process is thermal stripping of regenerable media containing the removed and concentrated contaminants. The fourth process is the production of hot regenerant gas by the inert gas generator for use by the stripper. The fifth process is the destruction of the spent regenerant gas stream in a small enclosed ground flare. Below is a schematic of the SWOP™ Process including the SAG™ final VOC polishing Process.



SWOP™ Process with SAG™ Final Polishing

### Legend

- 1 Raw LFG from moisture reduction processes
- 2 Contaminant concentrator vessel (siloxane and VOC removal)
- 3 Purified LFG to downstream processes
- 4 First SAG™ LFG polishing vessel
- 5 Second SAG™ LFG polishing vessel
- 6 Purified LFG for compression and conveyance to turbine
- 7 Spent media containing concentrated VOCs
- 8 VOC stripping column (media cleaning)
- 9 Cleaned media cooling column
- 10 Cleaned media returned to contaminant concentrator vessel
- 11 Purified LFG gas stream to hot inert gas generator
- 12 Hot inert gas generator (uses about 0.25% to 0.5% of purified gas flow)
- 13 Hot inert gas enters VOC stripping column
- 14 Hot waste gas stream containing stripped VOCs
- 15 Enclosed ground flare (uses about 0.5% to 1.0% of purified gas flow)
- 16 Purified LFG gas stream to ground flare (uses about 0.5 to 1.0% of purified gas flow)

Not shown on the drawing or in the legend are the blowers that transport the media and provide the combustion air. Total electrical consumption is less than 40 Kw. Also not shown on the drawing is the control panel. The Paris landfill SWOP™ system is not fully automated.

The newer SWOP™ Process is controlled by 3 PLCs—a main PLC, one for the hot inert gas generator, and one for the enclosed ground flare.

Below is a picture of the SWOP™ Process at the Paris landfill site. Please note that all piping and equipment connections had not yet been made at the time this picture was taken.



SWOP™ Process at Paris landfill

Construction and installation of the entire treatment process at the Paris landfill was completed in early 2005, and the system was started up in May of 2005. Unfortunately, due to downstream equipment problems with compressors, continuous flow of landfill gas was not able to be processed for long periods of time. Starting up and shutting down the SWOP™ Process has placed additional duty on the SAG™ Process (more frequent media replacements than originally planned). To date, the SWOP™ Process has removed over 80% of the VOCs, and 100% of the organosilicons. The original design was for the SWOP™ Process to remove > 95% of the VOCs, however some system components are not yet operating at full capacity. This is allowing the lighter fraction of the VOC to break through but be captured by the SAG™ Process. Nonetheless, the system has produced treated landfill gas with <math><0.005 \text{ mg/m}^3</math> organosilicons in it on a continuous basis since startup. See the data table below:

## SWOP™ System Performance

	Inlet	Outlet	% Removal
Selected VOCs	ug/m <sup>3</sup>	ug/m <sup>3</sup>	
α-Pinene	210,000	26,000	88%
Limonene	130,000	3,000	98%
2-Butanone (MEK)	74,000	65,000	12%
Toluene	61,000	28,000	54%
m- + p-Xylenes	62,000	5,000	92%
n-Nonane	84,000	2,300	97%
n-Decane	95,000	1,400	99%
1,4-Dichlorobenzene	2,700	100	96%
Butanoic Acid, Ethyl Ester	20,000	5,700	72%
C10 Alkanes	80,000	2,500	97%
<b>Total</b>	<b>818,700</b>	<b>139,000</b>	<b>83.0%</b>
Organosilicons (after SAG™ System)			
Decamethylcyclopentasiloxane (D5)	2,200	< 5	100
Octamethylcyclotetrasiloxane (D4)	5,900	< 5	100
Hexamethylcyclotrisiloxane (D3)	1,500	< 5	100
Octamethyltrisiloxane (MDM or L3)	62	< 5	100
Hexamethyldisiloxane (MM or L2)	1,500	< 5	100
Trimethylsilanol Si(CH <sub>3</sub> ) <sub>3</sub> OH	8,900	< 5	100
Tetramethylsilane Si(CH <sub>3</sub> ) <sub>4</sub>	76	< 5	100
<b>Total</b>	<b>20,138</b>	<b>&lt; 5</b>	<b>100%</b>

It was determined in the operation of the SWOP™ System over the last 9 months that if the media is not completely regenerated, then lighter VOCs will pass through to the SAG™ System. The SAG™ System is designed to remove whatever passes through the SWOP™ System. Additional process improvements will be made to the SWOP™ System at the Paris landfill to increase the removal of total VOCs to 90% or better on a continuous basis.

Some of the unexpected challenges at the Paris landfill include the number of shutdowns due to gas supply-related equipment, gas flow variations broader than planned for, and widely varying gas flow pressures. Based on the experience gained at the Paris landfill and during pilot testing in Washington and preliminary startup operations in South Carolina, approximately 40 process improvements have been made to the SWOP™ Process alone.

The entire landfill gas treatment system at the Paris landfill is seen in the picture below:



Complete landfill gas treatment package at Paris landfill (ground flare not shown).  
(Note that all piping had not been installed at the time the picture was taken)

The complete landfill gas treatment system includes:

- 1 Gas chilling to 38 degrees F. (3 to 4 degrees C.)
- 2 Water condensate removal
- 3 Gas reheat to approximately 77 degrees F. (25 degrees C)
- 4 Removal of siloxanes, organosilicons, and most VOCs by SWOP™ Process
- 5 Removal of any organosilicons and VOCs in SWOP™ Process effluent by SAG™ Process
- 6 > 99% Destruction of VOCs stripped from landfill gas by enclosed ground flare  
(the flare utilizes the energy in the stripped VOCs for their destruction, drawing supplemental energy from the purified landfill gas as needed).

The energy required (parasitics) to operate the SWOP™ Process is:

- 1 Electricity – about 8 Kw/h
- 2 Treated landfill gas – about 30 to 45 SCFM or around 0.7% to 1.0%)

The first of the two SWOP™ Systems in South Carolina was started up the week of February 6, however, at this writing no data are available. Operation of this system has been intermittent due to LFG supply issues. Below is a picture of the 2,500 SCFM capacity SWOP™ System with the gas conditioning package (by others) in the background. This is an extremely compact unit that sits on a 6 ft. wide x 12 ft. long skid (except for the flare).



Picture of 2,500 SCFM SWOP™ System at site in South Carolina

## Summary

The SWOP™ Processes at the landfill near Paris and at the South Carolina landfills are designed to remove siloxanes and organosilicon species as well as other VOCs from the landfill gas to prevent damage to the power generation equipment. In each case, the SWOP™ Systems provided superior technical and economic advantages over other gas treatment processes. Nine months operation for the world's first SWOP™ System has demonstrated total VOC reduction by a factor of 10 with the polishing media alone capable of a reduction factor of 5. very low consumption for auxiliary A huge benefit is very low consumption of power by the process. Full automation of the process is the key for day to day continuous operation.

The SWOP™ Process utilizes some of the purified landfill gas (around 0.5%) for continuous self-regeneration. VOCs and siloxanes are removed and concentrated into a small gas stream that is sent to an enclosed ground flare for destruction, thus eliminating this contamination.

The combination of SWOP™ and SAG™ technology allows reaching a level of siloxanes removal below detection. The development of SWOP™ + SAG™ system will allow establishing a new standard for low waste and low cost gas treatment.

The SWOP™ Process, coupled with the SAG™ Process, is an innovative biogas treatment technology that can produce virtually organosilicon-free and VOC free gas for power generation equipment. It is the most advanced biogas treatment technology in the world, and not only purifies the biogas, but also destroys the contaminants after they are removed. In the case of the Paris landfill, the annual volume of VOCs is about 280,000 pounds or 43,080 gallons (or about 163,000 liters) at an average liquid density of 6.5 pounds per gallon. Most of this volume of contaminants is destroyed in the ground flare, avoiding a future environmental clean-up problem. The contaminants themselves provide a large portion of the energy for their own destruction.

What makes the SWOP™ Process so efficient is its ability to regenerate the adsorbent media on a continuous basis so that it is always in a condition to remove as much of the organosilicons and VOCs as possible. Intermittently regenerated adsorbent media systems, such as those employing activated carbon or desiccant media, have significant breakthrough of VOCs even within hours of startup. This breakthrough increases with time as the media becomes saturated with VOCs. Depending on the time between regenerations, it is estimated that these systems can have breakthroughs of as much as 75% of the VOCs. Frequent regenerations drive up the cost of operation of these systems to a point where they can become uneconomical.

Additional information on the SWOP™ Process can be found on the AFT website at [www.appliedfiltertechnology.com](http://www.appliedfiltertechnology.com).

### Acknowledgements

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## Appendix A – Raw Paris Landfill Gas Analysis

<b>Gas Constituents</b>			
<b>Permanent Gases</b>	<b>% Volume</b>	<b>ppbv</b>	<b>Lb./Hour</b>
Methane	46 to 48	5.100.E+08	5.729E+03
Carbon Dioxide	36 to 38	3.600.E+08	1.112E+04
Nitrogen+Other Gases	10 to 12	1.200.E+08	2.359E+03
Oxygen	1.5 to1.8	1.800.E+07	4.044E+02
Water	0.4 to 0.6	3.957.E+06	5.000E+01
<b>VOCs, VICs</b>			
	<b>mg/m<sup>3</sup></b>	<b>ppbv</b>	<b>Lb./Hour</b>
Siloxane D5	2.20	132.98	0.0346
Siloxane D4	5.90	445.86	0.0928
Siloxane D3	1.50	151.11	0.0236
Siloxane MDM	0.06	5.88	0.0010
Siloxane MM	1.50	207.05	0.0236
Trimethylsilanol	8.90	2211.64	0.1400
Tetramethylsilane	0.08	19.31	0.0012
1,1,1-Trichloroethane	0.03	5.38	0.0005
1,1,2,2-Tetrafluoroethane (CFC 134a)	1.60	351.48	0.0252
1,1,2-Trichloro-1,2,2-trifluoroethane (CFC 113)	0.08	8.63	0.0012
1,1,-Difluoroethane (CFC 152a)	0.01	4.75	0.0002
1,1-Dichloro-1-fluoroethane (CFC 141b)	4.60	595.98	0.0724
1,1-Dichloroethane	0.28	63.42	0.0044
1,1-Dichloroethene	0.11	25.43	0.0017
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	0.30	39.34	0.0047
1,2-Dichloro-1,1,2-trifluoroethane (CFC ???)	0.03	4.25	0.0005
1,2-Dichloroethane	0.13	29.44	0.0020
1,2-Dichloropropane	0.18	35.71	0.0028
1,3-Oxathiolane	0.05	11.44	0.0007
1,4-Dichlorobenzene	1.50	228.71	0.0236
1,4-Dioxane	0.10	24.93	0.0015
1,4-Dioxolane	0.19	57.49	0.0030
1-Chloro,1-fluoroethane (CFC 151a)	0.43	116.78	0.0068
1-Chloro-1,1-difluoroethane (CFC 142)	0.48	107.03	0.0076
3-Carene	14.00	2303.32	0.2203
3-Methyl Thiophene	0.71	162.12	0.0112
Acetone	24.00	9262.02	0.3776
alpha-Pinene	200.00	32904.57	3.1471
alpha-Terpinene	1.30	213.89	0.0205
Benzene	4.90	1406.01	0.0771
beta-Pinene	24.00	3948.55	0.3776
Butanes, Butenes	25.29	9752.59	0.3979
Butanols	104.70	31660.41	1.6475
Butyl Acetate	10.70	2064.66	0.1684
Butyl Methyl Sulfide	0.75	161.31	0.0118
Butyl Propanoate	5.10	878.06	0.0802
Butyl-, Isobutly Butanoates	23.90	3714.60	0.3761
Butylbenzenes	11.00	1836.93	0.1731

VOCs, VICs	mg/m <sup>3</sup>	ppbv	Lb./Hour
Camphene	12.00	1974.25	0.1888
Camphor	6.00	883.39	0.0944
Carbon Disulfide	1.50	441.62	0.0236
Carvomenthone	0.50	73.61	0.0079
Chlorobenzene	0.68	135.48	0.0107
Chlorodifluoromethane (CFC 22)	0.54	139.92	0.0085
Chloroethane	0.06	19.11	0.0009
Chlorofluoromethane (CFC 31)	0.65	212.64	0.0102
Chlorotrifluoroethene (CFC 13)	0.04	8.15	0.0006
cis-1,2 Dichloroethene	5.20	1177.30	0.0818
Cycloalkane, C10	42.20	6743.22	0.6640
Cycloalkane, C11	0.95	138.00	0.0149
Cycloalkane, C5	9.90	5519.87	0.1558
Cycloalkane, C6	16.50	4402.75	0.2596
Cycloalkane, C7	14.40	3287.45	0.2266
Cycloalkane, C8	17.45	3485.65	0.2746
Cycloalkane, C9	45.00	7989.78	0.7081
Decahydronapthalene	2.50	405.31	0.0393
Decanes	249.00	39252.01	3.9181
Dichlorodifluoromethane (CFC 12)	2.70	500.56	0.0425
Dichlorofluoromethane (CFC 21)	6.60	1436.24	0.1039
Diethyl ether	0.91	275.18	0.0143
Dihydroindene (Indane)	0.75	142.25	0.0118
Dimethyl Disulfide	0.19	45.21	0.0030
Dimethyl ether	1.30	632.49	0.0205
Dimethyl Furan	2.60	606.23	0.0409
Dimethyl Sulfide	7.20	2597.49	0.1133
Dodecanes	5.80	763.18	0.0913
Ethanol	44.00	21392.97	0.6924
Ethyl Acetate	8.60	2187.80	0.1353
Ethyl Butanoate	35.00	6753.55	0.5507
Ethyl Furan	0.85	198.19	0.0134
Ethyl Hexanoate	4.50	699.40	0.0708
Ethyl Mercaptan	0.19	68.55	0.0030
Ethyl Methyl Sulfide	0.15	44.15	0.0024
Ethyl Pentanoate	4.70	809.19	0.0740
Ethyl Propanoate	10.00	2194.65	0.1574
Ethyl Toluenes	21.80	4034.46	0.3430
Furan	1.20	395.10	0.0189
Heptanes, Heptenes	31.25	6994.93	0.4917
Heptanones	1.10	219.80	0.0173
Hexanes, Hexenes	18.20	4732.42	0.2864
Hexanols	5.12	1122.48	0.0805
Hexanones	1.36	310.59	0.0214
Hydrogen Sulfide	280.00	184585.88	4.4059
Isopropyl butanoate	2.00	344.34	0.0315
Isopropyl Mercaptan	9.80	2884.30	0.1542
Isopropyl Methyl Sulfide	1.80	447.37	0.0283

<b>VOCs, VICs</b>	<b>mg/m<sup>3</sup></b>	<b>ppbv</b>	<b>Lb./Hour</b>
Limonene	150.00	24678.43	2.3603
Methyl Acetate	3.40	1028.72	0.0535
Methyl Butanoate	9.10	1997.14	0.1432
Methyl Ethyl Ketone (2-Butanone)	82.00	25491.65	1.2903
Methyl Furans	2.10	573.32	0.0330
Methyl Hexanoate	2.70	464.86	0.0425
Methyl Isobutanoate	0.62	136.08	0.0098
Methyl Mercaptan	0.53	246.96	0.0083
Methyl Pentanoate	1.96	378.20	0.0308
Methyl Propanoate	3.30	839.51	0.0519
Methyl tert-Butyl Ether	0.28	71.20	0.0044
Methylal	1.00	294.55	0.0157
Methyldecahydronaphthalenes	1.40	206.07	0.0220
Methylpropyl Sulfide	0.13	32.31	0.0020
mono-terpenes	5.40	888.47	0.0850
Naphthalene	0.02	3.15	0.0003
Nonanes, Nonenes	142.00	24815.71	2.2344
n-Propyl Mercaptan	0.19	56.04	0.0030
O+M+P Xylenes	87.00	18367.46	1.3690
Octanes, Octenes	42.74	8392.09	0.6725
p-Cymene	37.00	6178.77	0.5822
Pentanes, Pentenes	31.80	9878.80	0.5004
Pentanol	6.80	1728.77	0.1070
Pentanones (methyl, n-butyl ketone)	5.45	1418.28	0.0858
Propane Nitrile	0.02	7.32	0.0003
Propane, 2-ethoxy-2-methyl	0.28	61.42	0.0044
Propanols	43.00	16037.44	0.6766
Propyl butanoate	17.00	2926.86	0.2675
Propyl, Isopropyl Acetates	7.34	1610.81	0.1155
Propyl-, Isopropylbenzenes	10.70	1995.26	0.1684
Propylpropanoates	7.44	1003.61	0.1171
sec-Butyl Mercaptan	18.00	4473.70	0.2832
tert-Butyl Mercaptan	0.65	161.55	0.0102
Tetrachloroethene	8.60	1162.37	0.1353
Tetrahydrofuran	5.80	1803.07	0.0913
Tetramethyl Stannane	0.05	6.27	0.0008
Thiophene	0.49	130.59	0.0077
Toluene	72.00	17514.70	1.1329
trans-1,2-Dichloroethene	0.18	41.59	0.0028
Trichloroethene	4.60	784.73	0.0724
Trichlorofluoromethane (CFC 11)	2.40	391.23	0.0378
Tridecane	0.36	43.77	0.0057
Trimethyl Stibine	0.01	0.81	0.0001
Trimethylbenzenes	25.60	4773.94	0.4028
Undecanes	62.00	8890.43	0.9756
Vinyl Chloride	1.60	573.81	0.0252
<b>Totals (Excludes Hydrogen Sulfide)</b>	<b>2320.34</b>	<b>621423.31</b>	<b>32.11</b>

