



# VOCGEN CHP ENERGY SYSTEMS 2013

VOCGEN redefines air pollution control. The advanced economic model will revitalize industry.

INDUSTRIAL SECTORS

GOVERNMENT | MILITARY | CORPORATE



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# VOCGEN COMBINED HEAT AND POWER

ENVIRONMENT, ENERGY & ECONOMIC SECURITY

Steven E. Sexton



Environment & Power Systems International is pleased to announce a successful conclusion to the VOCGEN Energy Systems volatile organic compound performance trials and the commercial availability of our clean environment, energy and economic alternative for industry. (See Exhibit 1)

The VOCGEN product line is now commercially available to the numerous manufacturing, petrochemical, SOCM and other industrial sources of VOC emissions in the United States, subject to Title I, Part B of the U.S. Clean Air Act specific to Ozone Protection and subject to the requirements of a major source Title V Air Quality Operating Permit.

The gas turbine oxidizer (GTO) is configured for stoichiometric reaction of two (2) fuel types, including the opportunity waste fuel "VOC" and standard liquid and gaseous fuels typically used to operate the engine. The stoichiometric reaction is designed for the complete destruction and removal of the heat/fuel content of both the VOC and the fuel. The result is a replacement of traditional VOC air pollution control equipment such as the regenerative thermal oxidizer (RTO). The GTO is also fuel flexible with the capacity to utilize nine (9) different renewable and nonrenewable liquid and gaseous primary fuels while combusting the secondary fuel VOC.

Packaged within a state of the art portable power generator, the patented chamber is uniquely designed to efficiently combust regulated volatile organic compounds while the power generator supports a combined heat and power application



## PRODUCTS

### VOCGEN PORTABLE POWER GENERATOR PACKAGE

- 500 KILOWATT CLASS INDUSTRIAL GAS TURBINE
- CONTINUOUS AND INTERMITTENT DUTY
- SOUND-ATTENUATED ENVIRONMENTAL ENCLOSURE
- INTERMODAL TRANSPORTATION PACKAGE READY
- COMMERCIALY AVAILABLE COMPONENTS
- TURNKEY ENGINE AND CONTROLS SERVICES

## BUSINESS PARTNERS

PROVIDING PRODUCTS & SERVICES

[VERICOR POWER SYSTEMS](#) *World-Class Customer Support*

[PETROTECH, INC.](#) *Total Turnkey Services*

[ENERCON ENGINEERING](#) *Manufacturing & Engineering Services*

[GLHN ARCHITECTS & ENGINEERS](#) *Energy Engineering & Commissioning*

## PUBLICATIONS

- [VOCGEN.COM](#)
- [WHITE PAPERS](#)
- [VOCGEN WEB LOG AT WORDPRESS](#)
- [PROJECT SITE SELECTION GUIDELINES](#)
- [PROJECT SCREENING & FEASIBILITY](#)
- GTO TECHNICAL ASSESSMENT\*
- VOCGEN POWER GENERATOR FUNCTIONAL SPECIFICATIONS\*  
\* [Gas Technology Institute](#)

## STATE ENERGY EFFICIENCY INCENTIVE PROGRAMS

[PROJECT REBATES FOR COMBINED HEAT AND POWER APPLICATIONS](#)

Database of State Incentives for Energy Efficiency CHP Projects (DSIRE)



## VOCGEN GTO OVERVIEW

An aero-derived industrial gas turbine, the 500 kW-class ASE8 by Vericor Power Systems is designed for continuous or intermittent operations and it can accommodate frequent starts and stops in support of variable shift production operations. The gas turbine system has a fast start capability, reaching a maximum power load in less than 2 minutes, with an excellent fuel efficiency of 85% when configured in combined heat and power (CHP) applications.

Environment & Power Systems International and our business partners offer full product and project engineering support in customized solutions that can meet your specific requirements. Automation and controls are professionally integrated with your production facilities and each individual component can be selected according to your requirements. In addition, the compact design of our equipment enables us to accommodate tight space constraints common in retrofit projects including roof-mount options, eliminating the high cost of long duct, fan, utility, trestle and civil infrastructure.

With engine support extending well beyond the sale, Vericor Power Systems offers gas turbine after-sales service and support including rapid delivery of spare parts, 24-hour emergency services and remote diagnostics, as well as complete overhauls of your gas turbine. To protect your investment, Environment & Power Systems and Vericor offer full maintenance contracts for up to 10 years, tailored to your specifications.

## PRODUCT PURPOSE AND MISSION

Meeting today's rigorous clean air standards has created technical and economic challenges for many companies whose manufacturing processes have the potential to emit volatile organic compounds (VOC) into the atmosphere. The drive towards environmentally-friendly compliant coatings and production materials, which reduce VOC emissions, has been only partially successful and many companies find that they need to use traditional VOCs in quantities required to maintain the quality and functionality of their products. With the exception of a few industries where heat recovery and re-use is practical, most VOC abatement technology involves the destruction of VOC by thermal oxidation with no real economic benefit, or value added from the abatement system. Now, a patented adaptation of an aero-derived gas turbine engine, fitted with the VOC reaction chamber, or Gas Turbine Oxidizer (GTO), is linked to an electric generator offering a means to effectively destroy

VOC and at the same time provide a payback by reducing the cost of operations.

The industrial gas turbine selected is an adaptation of a well-established turboprop engine from a GTCP 331 series airborne Auxiliary Power Unit (APU), of which over 10,000 are in service worldwide. To make the engine suitable for VOC destruction, it has been fitted with a specially developed combustor, proficient in the combustion of a wide range of VOC under conditions of low nitrogen oxides (NOx) generation and virtually 100% VOC destruction in the combustor. The gas turbine powered generator sets are provided as portable packaged units complete with sound attenuated environmental enclosures, fully automated electronic controls, safety interlocks and flexible, multilingual operator interfaces including real-time control and monitoring designs founded on open architecture logarithms' that allow for seamless integration with third-party Human Machine Interface (HMI) packages and devices.

The engine can handle airflow of 10,500 m<sup>3</sup>/hr (6200 CFM at ISO conditions) and can generate 525 kW (705 SHP) and up to 1,818 kg/hr (4,000 lbs/hr) of byproduct steam. The value of electricity generated and heat/steam produced will reduce the cost of operating this VOC abatement system; and depending on the relative cost of electric power and auxiliary fuel, the engine installation can generate a net positive cash flow, which is particularly appealing for small cogeneration installations.

## ECONOMICS

Current VOC abatement technology is focused on the destruction of VOC by thermal oxidation directly through the use of heat, by removal at low temperature using physical adsorption and or chemical or biochemical oxidation techniques. Only in a few cases is recovery and re-use feasible. Nevertheless, these technologies rarely provide a financial return to the end-user and are, but a drain on capital and operating resources.

The development of a gas turbine engine capable of VOC destruction and producing usable electrical and thermal energy for the end-user now provides a system which will serve both the community in providing cleaner air and also the owner, which benefits from a return on the money spent on capital and operating costs.

VOCGEN energy recycling marks the end of an era of high cost VOC abatement. The technology eliminates the life-cycle cost of traditional volatile organic compound (VOC) air pollution control equipment, creating an enhanced cogeneration economic model,



realized by a quick return on capital investment, united with significant annual operational cost savings for the life of the project estimated at 20-30 years.

The VCOGEN CHP solution delivers a superior cost savings model for over 100 discrete industrial categories subject to the requirements of the Clean Air Act.

## **GAS TURBINE OPERATION**

The gas turbine used is a single shaft engine with a two-stage centrifugal compressor section, and a three stage axial turbine, mounted with the combustor, lube oil, fuel system and starter on a gear box designed to provide 3600, 1800 or 1500 rpm output to the generator depending on the application.

The VOC-laden air is compressed to about 620kPa (130 psig) in the centrifugal compressor and enters the combustor at a temperature of around 315°C (600°F). Fuel is added in the combustor as necessary to provide sufficient energy to destroy the VOC. The combustion gases pass from the combustor through the turbine, expanding and cooling to drive the turbine, compressor and generator. The turbine exhaust exits at a temperature of 500°C (925°F), sufficient to generate 100 to 1000kPa (15 to 150psig) steam efficiently in a heat recovery boiler.

The turbine, generator and all associated controls are packaged in a weatherproof housing only requiring hook-up to fuel, process air containing VOC, and a simple connection to the plant electrical system.

The turbine runs at a fixed speed synchronized to the plant AC frequency of 50 or 60 Hertz, and processes in fixed volume, 10,500 m<sup>3</sup>/hr (6200 ft<sup>3</sup>/min) VOC laden air flows.

A heat recovery boiler can be provided to recover thermal energy from the engine exhaust, or waste heat can be applied to heat exchangers, and/or chillers for refrigeration.

The system is pre-engineered and standardized to provide safe and reliable operation in an outdoor location without operator attendance. The system is designed to be operated by remote control from a central control panel onsite via the internet.

## **GAS TURBINE TECHNICAL ADVANCES FOR VOC CONTROL**

Recent developments in gas turbine (GT) technology have allowed the modification of certain gas turbines for use in volatile organic compound (VOC) destruction. Traditional gas turbines range from relatively low firing temperature 950°C (1750°F) in the smallest sizes to well over 1430°C (2600°F) for the most sophisticated large turbine engines.

It has been well understood for a number of years that destruction temperature could be traded for turbulence and residence time. When the destruction device accomplishes no useful purpose beyond the destruction of volatiles, the design goal is to get to the lowest possible temperature and thereby the lowest need to provide supplemental fuel beyond the VOC itself. Thermal oxidizers, both Recuperative and Regenerative, range from firing temperatures of 675°C (1250°F) to 870°C (1600°F) with residence times up to a second or more.

Turbine Generators on the other hand provide electricity; a high value commodity priced at 5 to 12 times the price of natural gas on unit energy basis. Thus, the gas turbine can operate at a higher firing temperature than is commonly accepted for thermal incinerators. At the same time, the residence time can be significantly lower.

## **GAS TURBINE**

The gas turbine in its simplest form consists of:

- A compressor to draw the air in and raise it to high pressure
- A combustor to heat the air through the introduction of fuel and
- A turbine to provide shaft power to drive the compressor.

Power for a generator can be taken from the turbine shaft. Alternatively, it can be left in the form of high pressure hot air for the thrust of a jet engine or even a second power turbine dedicated to providing external power for a propeller, pump, or generator.

Combustors used for gas turbines have residence times in the milliseconds, far too short to complete destruction of VOCs. Therefore, the first requirement is to add a reaction chamber between the combustor and the turbine to extend residence time. Residence time in the turbine is approximately ½ second at a 1010°C (1850°F) average firing temperature. In addition, the device is so constructed that it is extremely turbulent and therefore well mixed. The result is that VOCs are virtually 100% destroyed in the reaction chamber.

This reaction chamber is far smaller than the smallest thermal oxidizer, due to the high pressure and density in the chamber. However, it is still much larger than the normal gas turbine combustor.

## **TEMPERATURE LIMITATIONS**

Gas turbine combustors used at the highest temperature owe their survival to high temperature super alloys and the judicious use of compressor discharge air to cool the combustor walls. Cooling air is



unacceptable when using reaction chamber technology for two reasons:

Any cooling air introduced in the reaction chamber bypasses the destruction process and will have lower destruction efficiency than core air.

The surface area of the reaction chamber is so large that cooling to allow operation at high temperature is impractical.

Therefore, turbine-firing temperatures beyond 1150°C (2100°F) are impractical for use as a VOC destruction device.

Higher turbine firing temperature produce more power from a given volume of air and are therefore less suited to VOC destruction.

### **TURBINE COOLING**

Another design constraint introduced by adding volatile organic destruction to tasks of a gas turbine engine has to do with cooling flows. Cooling flow is compressor discharge air that is routed to parts of the combustor and turbine requiring local cooling. A low temperature turbine has only small amounts of flow used to purge turbine disk cavities and leakage in the combustor joint areas.

As the turbine temperature rises, turbine stators and turbine rotors become air-cooled. Turbines with these sophisticated cooling features are unusable for controlling volatile organic compounds due to the large amounts of air that bypass the heart of the destruction process. In converting the turbine to its use for VOC destruction, the internal static seal system was redesigned using a mustache seal to reduce leakages typical of low temperature turbines.

The result is that turbines that are to be used for VOC destruction must be designed – not adapted to the task. Relatively low turbine firing temperature makes the task of providing reaction chambers for a higher residence time and controlling cooling bypasses practical.

The development of this system occurred over a two year period with continuing testing of a variety of typical VOCs. The size of the reaction chamber was changed and the internal seals were modified and redesigned to use the close-fitting mustache seals.

The end result of making these kind of changes is a system that has been stack tested on pentane, methylene chloride, toluene, xylene, ethanol, mineral and ink oil (molecular weight 140), Stoddard fluid, hexane, and other similar compounds. Testing on these materials proved destruction efficiencies above 98% with pentane testing at 98.98%. Further improvements in destruction efficiency in the future are likely by utilizing external air sources for turbine cooling air.

### **VOC EMISSIONS PERFORMANCE**

The specially developed combustor for the turbine combines operation at elevated temperature and pressure with an efficient swirl pattern to provide essentially 100% destruction of the VOC in the combustor. A very small amount of the inlet stream is bypassing the combustor to provide hub cooling for the turbine, so that a typical overall Destruction and Removal Efficiency (%DRE) for the turbine is about 98%. This performance is comparable to conventional VOC oxidation equipment.

In addition, the turbine operates with a very low NO<sub>x</sub> (Oxides of Nitrogen) generation of less than 30 PPM and a CO (Carbon Monoxide) emission of less than 10 PPM.

### **ROTOR CONCENTRATOR/GAS TURBINE ENGINE COMBINATION FOR INCREASED AIR FLOW CAPACITY**

This turbine has a fixed air flow capacity of 10,500m<sup>3</sup>/hr (6200ft<sup>3</sup>/m) and thus is not a “one size fits all” device. The use of this turbine can be significantly extended to larger flows by concentrating VOCs before the turbine. The most suitable device for this duty is a hydrophobic zeolite rotor concentrator. The rotor concentrator is essentially a corrugated fiber matrix structure impregnated with a zeolite adsorbent. The concentrator is capable of treating VOC streams with an inlet concentration of up to about 500 PPM generating a cleaned effluent stream meeting standard DRE requirements and delivering a concentrate to the turbine inlet that is about 1/10th of the original stream.

In addition to making the turbine suitable for a wider range of airflows, the use of a concentrator has the additional benefit of providing a higher VOC content to the turbine, reducing the consumption of support fuel. The rotor concentrator/engine combination will handle VOC flows from 10,500m<sup>3</sup>/hr (6200 CFM), and in some cases, more in a single equipment train. The capacity limits of the rotor concentrator are primarily inlet temperatures and concentration. The rotor operates with an inlet temperature of 38°C (100°F) or less and was specifically designed to handle large volume dilute flows. This fits very well with the current emphasis on treating this type of flow, and provides an additional financial incentive to industry not offered by conventional technologies.

Semiconductor manufacture, spray painting, printed circuit board production, aircraft stripping and painting, flow coating, gravure coating, and secondary VOC exhaust are some of the more obvious applications for this combination of technologies.

By combining the fixed flow, air-cooled gas turbine engine with a rotor concentrator, the Gas Turbine Oxidizer (GTO) has a wide field of applications in industrial VOC abatement.

### **ECONOMIC COMPARISONS WITH TRADITIONAL VOC DESTRUCTION TECHNOLOGIES**



To get a picture of the relative economic merits of the Gas Turbine Oxidizer, the following tables detail the operating costs of three common solutions to a typical industrial VOC abatement application:

- Gas turbine oxidizer with rotor concentrator
- Regenerative thermal oxidizer
- Recuperative catalytic oxidizer

The application is representative of paint finishing and semiconductor manufacturer VOC exhausts. The VOC mixture is 40% xylene, 25% Butanol, 20% MEK, 10% Isopropanol and 5% Methylene

Chloride. Although the chemistry will vary from one application to another, the VOC species are representative of the physical characteristics of boiling point, molecular weight, adsorption performance and fuel value which influence the performance and economics of the system.

Table 1 shows the relative economics at a fuel cost of \$3.50 per million BTU of gas and electric power at \$0.09 per kWh as is common in New England and the Southwestern USA and other parts of the World.

<b>Table 1</b>	<b>Rotor/GTO</b>	<b>RTO</b>	<b>Rotor/Catalytic Oxidizer</b>
Inlet Flow	30,000 ACFM	30,000 ACFM	30,000 ACFM
Inlet Temperature	75°F	75°F	75°F
VOC Load	40lbs/hr	40lbs/hr	40lbs/hr
Electric Power	+525kW	-138kW	-36kW
Fuel Consumption	8.77 MMBTU/HR	1.8 MMBTU/HR	0.7 MMBTU/HR
<b>Thermal Energy Produced</b>	<b>4.5 MMBTU/HR</b>	<b>0.0 MMBTU/HR</b>	<b>0.0 MMBTU/HR</b>

As can be seen from the table, the Gas Turbine Oxidizer combined with a rotor concentrator yields a net return on the investment, compared to the other technologies. The operating costs for the RTO and Rotor/Catalytic Oxidizer systems vary in a direct relationship with the inlet flow. The turbine operating costs and benefits are fixed for a single engine, so that the Turbine/rotor combination cost/benefits stay relatively constant for flows that can be concentrated to suit a single engine. In practical terms, this includes flows from about 20,000 CFM to 75,000 CFM.

The installed cost of the engine/rotor combination increases less with an increase in flow than the other technologies, so the economics improve as the flow approaches the upper range of what can be concentrated to suit a single engine.

The system designs and the inlet flow is exactly the same as Table 1, but the electric costs are \$0.06 per kWh which is representative of many other parts of the USA

The cost of electricity and fuel are the significant factors which impact the economic comparison of grid power to CHP. This comparison must be conducted on a case-by-case basis to provide an accurate picture of the relative merits of a CHP project.

**SUITABLE GAS TURBINE APPLICATIONS**

The gas turbine by itself is suitable for applications up to 10,500 m<sup>3</sup>/hr (6200 CFM) or multiples thereof. The turbine can handle any inlet concentration including rich streams with VOC concentration up to about 50% of the lower explosive level (LEL) and very rich streams

with concentrations well above the higher explosive limit. Examples of rich stream exhausts include process vent condensers, autoclave exhausts, and tank breathing vents, bulk storage terminals, byproduct gases from chemical plants and similar applications. When teamed with a rotor concentrator, the systems applications move into the mainstream of current VOC abatement including automotive spray finishing, furniture finishing, coating and printing applications, and any other surface coating application using VOC based coatings.

The semiconductor industry is a special application where the standby generating capacity of the GTO generator is of additional benefit. Semiconductor plants suffer significant economic effects of power outages and often invest in significant diesel powered standby generating capacity. The GTO generator can replace or augment some of this generating capacity at no additional cost as long as there is some power on line to provide excitation for the induction generator.

**REGULATORY ISSUES**

The GTO meets all the current standards for VOC oxidation systems, co-generation turbines, industrial boilers and furnaces and fuel fired process heaters. The rotor concentrator/GTO combination can be designed to meet the current standards for rotor/oxidizer combinations of ≥96% DRE in general, and more stringent standards in certain parts of the USA. The addition of supplementary controls, such as water injection to reduce NOx can further reduce the GTO emissions to meet the most stringent requirements.

## **ADDITIONAL CONSIDERATIONS**

The power produced by the GTO is generally used within the facility, not delivered to the power grid, so the system is not considered a co-generating plant from a regulatory standpoint. The only effect on the electric utility is reduced consumption of power delivered.

The GTO package is quiet. The perception that gas turbines make a lot of noise relates to aircraft turbines, where high velocity exhaust is used to propel the aircraft. The high frequency noise from the turbine is much easier to attenuate with simple low-pressure mufflers than low frequency noise from reciprocating engines. Standard noise level measurements 1 meter from the GTO enclosure is 85 dbA.

Typical GTO exhaust emissions are about 40 PPM NO<sub>x</sub> and about 10 PPM CO. This is comparable to the performance of low NO<sub>x</sub> burners. It is less than coal fired power generation plant emissions, and comparable to gas fired power generation plants.

The VOC DRE performance of the GTO can be designed to meet local permit conditions. Both the GTO and the rotor concentrator are routinely specified to individually reduce the VOC emission by 96-99%. In combination, the resulting system typically has a DRE of 96% and can be designed to meet more stringent regulations by process changes size selection, water injection or addition of a post combustion exhaust oxidation catalyst.

## **FUNDING**

Technical development, market investigations, industry applications, regulatory research and the enhanced VOC/CHP economic model created by the patented Gas Turbine Oxidizer and Power Generator has been privately funded. No government funding has been identified for the development of the new commercial product.

## **CONCLUSION**

The GTO offers an opportunity to effectively abate VOC emissions while generating usable and valuable clean energy byproducts. Used for suitable applications the GTO can generate a net positive cash flow for the owner in addition to providing a cleaner environment and compliance with air pollution regulations.

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# VOCGEN CHP Level One Project Feasibility Financial Summary



## Expanded Foam Manufacturing Company State of California DR/SS

Operational Costs	Air Pollution Control Equipment & Utility Supplied Energy	VOCGEN CHP Equipment
Natural Gas	(\$387,526)	(\$405,861)
Electricity	(\$94,610)	\$0
Maintenance	(\$25,000)	(\$47,250)
Plant Natural Gas	(\$412,009)	
Plant Electricity	(\$477,314)	
	(\$1,396,459)	(\$453,111)
<b>Annual Savings</b>		<b>\$943,348</b>
<b>Capital Equipment</b>		
Regenerative Thermal Oxidizer (RTO)	(\$2,275,000)	\$2,275,000
VOCGEN CHP System	\$0	(\$3,489,900)
	(\$2,275,000)	(\$1,214,900)
Simple Payback Period	None	<b>1.29-year payback</b>
<b>Potential savings over 20-years</b>		<b>\$19,202,056</b>
<b>Internal Rate of Return</b>		<b>78%</b>
<b>Net Present Value (NPV)</b>		<b>\$6,678,689</b>
<b>Carbon Dioxide Emissions (MT)</b>	7,180	4,568
<b>Carbon Equivalent Emissions (MT)</b>	1,958	1,246
<b>Annual Carbon Reduction</b>		<b>63.62%</b>





**Expanded Foam Manufacturing Company Example Level One (1)  
Cost Benefit Analysis**

VOC loading Rate	120 lb/hr
Plant location	California
Natural Gas Price	\$6.99 USD/MMBtu
Electricity Price	\$0.123 USD/kWh

US Energy Information Agency - Energy Prices June - 2013..... Pentane - VOC Heat Content 19,500 Btu/tb

**RTO - Regenerative Thermal Oxidizer Air Pollution Control Equipment & Utility Supplied Energy - Option 1**

**VOCGEN CHP Equipment Option 2**

**Equipment Selection**

**VOCGEN Equipment Selection**

**Equipment Option 1**

RTO - Regenerative Thermal Oxidizer (50) KCFM at 80°F  
Other Equipment

1	Unit(s)
0	Unit(s)

**VOCGEN Genset -\*0.560 MW  
VOC Concentrator | HRSG**

\* Nominal rating

560 kW per gas turbine

1	Unit(s)
1	Unit(s)

**Operating Hours**

**VOCGEN Operating Hours**

(RTO - Regenerative Thermal Oxidizer)  
Operating hours

7,920	hr/yr
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(8hrs/shift, 3shifts/day, 330days/yr)

**Genset(s) Operating hours**

8,712	hr/yr
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(8hrs/shift, 3shifts/day, 363days/yr)

**Air Flow**

**VOCGEN Air Flow**

System airflow (CFM)

50,000	CFM
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Other

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**VOCGEN Genset(s) - CFM ISO Cond.**

6,200	CFM/genset
6,200	CFM

**Elevation: 250 Feet**

**1. Fuel**

**1. VOCGEN Fuel**

System operating hours  
(8hrs/shift, 3shifts/day, 330days/yr)

7,920 hrs/yr

Regenerative Thermal Oxidizer fuel requirement

7.00 MMBtu/hr

Other equipment fuel requirement

0.00 MMBtu/hr

**Estimated Fuel Required**

Annual Carbon Reduction

**Equipment Option 1**

RTO - Regenerative Thermal Oxidizer (50) KCFM at 80°F

(\$387,526) USD

Other Equipment

\$0 USD

Total Natural Gas usage by Option 1

(\$387,526) USD/yr

**VOC Energy Contribution**

Operating hours (VOC production)

(8hrs/shift, 3shifts/day, 330days/yr) 7,920 hrs/yr

VOC load 120 lb/hr

Heat content 19,500 Btu/lb

18,533 MMBtu/yr

Natural gas pilot fuel use is regulated by an automated system compensating for VOC heat content contribution.

**Natural Gas Fuel**

**VOCGEN Genset(s) 0.560 MW**

Heat rate

15,700 Btu/kWh

8.79 MMBtu/hr/genset

8.79 MMBtu/yr

76,596 MMBtu/yr



<p><b>Estimated Fuel Required</b></p> <table border="1"> <tr> <td>Natural Gas</td> <td>55,440 MMBtu/yr</td> </tr> <tr> <td><b>Total fuel</b></td> <td><b>(\$387,526) USD/yr</b></td> </tr> </table>	Natural Gas	55,440 MMBtu/yr	<b>Total fuel</b>	<b>(\$387,526) USD/yr</b>	<p><b>Estimated Fuel Required</b></p> <table border="1"> <tr> <td>VOC</td> <td>18,533 MMBtu/yr</td> <td>\$129,544 USD/yr Savings</td> </tr> <tr> <td>Natural Gas</td> <td>58,063 MMBtu/yr</td> <td>(\$405,861) USD/yr</td> </tr> <tr> <td><b>Total fuel</b></td> <td><b>76,596 MMBtu/yr</b></td> <td><b>Cost (\$405,861) USD/yr</b></td> </tr> </table>	VOC	18,533 MMBtu/yr	\$129,544 USD/yr Savings	Natural Gas	58,063 MMBtu/yr	(\$405,861) USD/yr	<b>Total fuel</b>	<b>76,596 MMBtu/yr</b>	<b>Cost (\$405,861) USD/yr</b>
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<p><b>2. Regenerative Thermal Oxidizer Electrical Cost</b></p>	<p><b>2. VOCGEN Parasitic Loads</b></p>													
<p><b>Estimated RTO Electricity Cost</b> <i>Using total motor Hp of 97.5 &amp; power draw of 0kW</i></p> <table border="1"> <tr> <td>772,329 kWh/yr</td> </tr> <tr> <td><b>(\$94,610) USD/yr</b></td> </tr> </table>	772,329 kWh/yr	<b>(\$94,610) USD/yr</b>	<p><b>VOCGEN Genset(s) 0.560 MW</b></p> <p>Chiller 0 kW/unit 0 kW - parasitic load</p> <p>NG Booster Compressor 50 kW/unit 50 kW - parasitic load</p> <p><b>Estimated Operation Electricity Use From Parasitic Load</b></p> <table border="1"> <tr> <td>50 kW</td> </tr> <tr> <td><b>435,600 kWh/yr</b></td> </tr> </table>	50 kW	<b>435,600 kWh/yr</b>									
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<p><b>4. Avoided Electrical Requirements of Facility</b></p> <table border="1"> <tr> <td>510 kW 3,896,442 kWh/yr</td> <td>VOCGEN Cost Avoidance <b>(\$477,314) USD/yr</b></td> </tr> </table>	510 kW 3,896,442 kWh/yr	VOCGEN Cost Avoidance <b>(\$477,314) USD/yr</b>	<p><b>4. VOCGEN Electrical Output Contribution (Less Parasitic Load)</b></p> <table border="1"> <tr> <td>(560kW - 50kW)</td> <td>510 kW</td> </tr> <tr> <td></td> <td><b>3,896,442 kWh/yr</b></td> </tr> </table> <p><i>Altitude factor at 250ft is 0.993 of nominal output power VOCGEN parasitic load deducted from total electrical output</i></p>	(560kW - 50kW)	510 kW		<b>3,896,442 kWh/yr</b>							
510 kW 3,896,442 kWh/yr	VOCGEN Cost Avoidance <b>(\$477,314) USD/yr</b>													
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<p><b>5. Avoided Natural Gas Requirements for Heating/Cooling</b></p> <table border="1"> <tr> <td>58,943 MMBtu/yr</td> <td>VOCGEN Cost Avoidance <b>(\$412,009) USD/yr</b></td> </tr> </table>	58,943 MMBtu/yr	VOCGEN Cost Avoidance <b>(\$412,009) USD/yr</b>	<p><b>5. VOCGEN Heat Output Contribution</b></p> <table border="1"> <tr> <td>VOCGEN Genset(s) 0.560 MW</td> </tr> <tr> <td>8.79 MMBtu/hr Fuel</td> </tr> <tr> <td>1.85 MMBtu/hr Electrical power</td> </tr> <tr> <td>6.95 MMBtu/hr Heat</td> </tr> <tr> <td>6.77 MMBtu/hr Heat w/radiated heat loss</td> </tr> <tr> <td><b>58,943 MMBtu/yr nominal heat</b></td> </tr> </table>	VOCGEN Genset(s) 0.560 MW	8.79 MMBtu/hr Fuel	1.85 MMBtu/hr Electrical power	6.95 MMBtu/hr Heat	6.77 MMBtu/hr Heat w/radiated heat loss	<b>58,943 MMBtu/yr nominal heat</b>					
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<p><b>Regenerative Thermal Oxidizer annual operating cost</b></p> <p>(VOCGEN cost avoidance included in Regenerative Thermal Oxidizer annual operating cost below)</p>	<p><b>VOCGEN Carbon Emissions Reductions - Potential</b></p> <table border="1"> <tr> <td>Federal Proposed Value</td> <td>712 ton Carbon/year \$0.00 USD/ton</td> <td><b>\$0 USD/yr</b> <b>Not included in total savings</b></td> </tr> </table>	Federal Proposed Value	712 ton Carbon/year \$0.00 USD/ton	<b>\$0 USD/yr</b> <b>Not included in total savings</b>										
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6. Capital Equipment Budget- First year	6. VOCGEN Capital Equipment Budget- First year
<p><b>Equipment Option 1</b></p> <p>RTO - Regenerative Thermal Oxidizer (50) KCFM : (\$1,750,000) USD Other Equipment \$0 USD</p> <p>Two Additional 'RTO' unit(s) will be purchased during the 20-year evaluation period with installation costs included (factor: 1.30): (\$2,275,000) USD</p>	<p><b>Equipment Option 2</b></p> <p>0.560MW VOCGEN Genset cost (\$1,723,000) USD</p> <p>Equipment Package Engineering and Designs w/Specifications and Operations Manual Skid-mounted equipment enclosure Natural Gas Booster Compressor and Receiver Tank (optional) D.I. Water Purification System (optional) Electric Chiller (300°F to 65°F) Honeywell Catox Air Purification Catalyst (optional)</p> <p><i>Functional Specification for 4160 VAC 560 kW Gas Turbine Designed by EPSI and Gas Technology Institute 1700 South Mount Prospect Road Des Plaines, IL 60018-1804</i></p>
<p><b>Estimated Equipment Costs</b></p> <p style="text-align: right;">(\$1,750,000) USD/yr</p>	<p><b>Estimated Equipment Cost</b></p> <p style="text-align: right;">(\$1,723,000) USD</p>
<p>Installation (est. 30% of equipment)</p> <p style="text-align: right;">(\$525,000) USD</p>	<p><b>Estimated Project Costs</b></p> <p>Installation (est. 30% of equipment) Const. Mgmt., Subcontractors and Suppliers Engineering, Civil, Mechanical, and Electrical Heat utilization VOC Concentrator   HRSG</p> <p style="text-align: right;">(\$516,900) USD</p> <p style="text-align: right;">(\$1,500,000) USD</p>
<p><b>Estimated Capital Equipment Costs</b></p> <p style="text-align: right;">(\$2,275,000) USD</p>	<p><b>Estimated Capital Equipment Costs</b> <i>(Rebate of \$250,000 subtracted from the cost)</i></p> <p style="text-align: right;">(\$3,489,900) USD</p>
<p><b>Year Zero Avoided Costs</b></p> <p style="text-align: right;">\$2,275,000 USD</p>	<p><b>Adjusted First Year Costs</b></p> <p style="text-align: right;">(\$1,214,900) USD</p>



7. Cash Flow

	Equipment Option 1	VOCGEN Equip. Option 2	
	Each year	Each year	Difference
Year 0	(\$2,275,000)	(\$3,489,900)	(\$1,214,900)
Year 1	(\$1,396,459)	(\$453,111)	\$943,348
Year 2	(\$1,396,459)	(\$453,111)	\$943,348
Year 3	(\$1,396,459)	(\$453,111)	\$943,348
Year 4	(\$1,396,459)	(\$453,111)	\$943,348
Year 5	(\$1,396,459)	(\$453,111)	\$943,348
Year 6	(\$1,396,459)	(\$453,111)	\$943,348
Year 7	(\$1,396,459)	(\$453,111)	\$943,348
Year 8	(\$3,671,459)	(\$1,953,111)	\$1,718,348
Year 9	(\$1,396,459)	(\$453,111)	\$943,348
Year 10	(\$1,396,459)	(\$453,111)	\$943,348
Year 11	(\$1,396,459)	(\$453,111)	\$943,348
Year 12	(\$1,396,459)	(\$453,111)	\$943,348
Year 13	(\$1,396,459)	(\$453,111)	\$943,348
Year 14	(\$1,396,459)	(\$453,111)	\$943,348
Year 15	(\$1,396,459)	(\$453,111)	\$943,348
Year 16	(\$3,671,459)	(\$1,953,111)	\$1,718,348
Year 17	(\$1,396,459)	(\$453,111)	\$943,348
Year 18	(\$1,396,459)	(\$453,111)	\$943,348
Year 19	(\$1,396,459)	(\$453,111)	\$943,348
Year 20	(\$1,396,459)	(\$453,111)	\$943,348

Simple Payback 1.29 years

Potential savings over 20-years  
\$ 19,202,056

IRR 78%

Example

Discount Rate 10%  
Net Present Value \$6,678,689 USD



### Carbon Emissions Impact

Emissions from Natural Gas		VOCGEN Natural Gas Emissions	
<b>Equipment Option 1</b>			
RTO - Regenerative Thermal Oxidizer (50) KCFM :	1,040 MT CO <sub>2</sub> / year	Total usage	17,016,624 kWh/year
Other Equipment	MT CO <sub>2</sub> / year	Carbon emissions from natural gas	0.185 kg CO <sub>2</sub> /kW
CO <sub>2</sub> emissions	1,040 MT CO <sub>2</sub> / year	CO <sub>2</sub> emissions	3,148,075 kg CO <sub>2</sub> /year
	945,791 kg CO <sub>2</sub> / year	Carbon equivalent	858,566 kg Carbon/year
Carbon equivalent	284 MT Carbon/year		
	257,943 kg Carbon/year		
Emissions Avoided by On-Site Energy Generation		VOCGEN VOC Emissions	
Grid supplied electricity avoided	510 kW	Total usage	5,431,430 kWh/year
	4,443,120 kWh/year	Carbon emissions from natural gas	0.185 kg CO <sub>2</sub> /kW
	4,443 MWh/year	CO <sub>2</sub> emissions	1,004,815 kg CO <sub>2</sub> /year
Carbon emissions from grid electricity	0.537 kg CO <sub>2</sub> / kW	Carbon equivalent	274,040 kg Carbon/year
CO <sub>2</sub> emissions	2,385,955 kg CO <sub>2</sub> / year		
Carbon equivalent	650,715 kg Carbon/year		
Emissions Avoided by On-Site Heat Generation		VOCGEN Electricity Generated	
Natural gas usage avoided	17,274,380 kWh/year	Total electricity generated	510 kW
Carbon emissions from natural gas	0.185 kg CO <sub>2</sub> / kW	Parasitic load	50 kW
CO <sub>2</sub> emissions	3,195,760 kg CO <sub>2</sub> / year	Theoretical - total electricity available	460 kW
Carbon equivalent	871,571 kg Carbon/year	Actual - total electrical available	456 kW
			3,976,418 kWh/year
			3,976 MWh/year
			No carbon emissions (see natural gas above)
Emissions Avoided by On-Site Heat Generation		VOCGEN Heat Generated	
Natural gas usage avoided	17,274,380 kWh/year		17,274,380 kWh/year
Carbon emissions from natural gas	0.185 kg CO <sub>2</sub> / kW		No carbon emissions (see natural gas above)
CO <sub>2</sub> emissions	3,195,760 kg CO <sub>2</sub> / year		
Carbon equivalent	871,571 kg Carbon/year		
<b>Estimated CO<sub>2</sub> emissions (Metric Tons - MT)</b>	<b>6,527,507 kg CO<sub>2</sub> / year</b>	<b>Estimated CO<sub>2</sub> emissions (Metric Tons - MT)</b>	<b>4,152,890 kg CO<sub>2</sub> / year</b>
	<b>7,180 MT CO<sub>2</sub> / year</b>		<b>4,568 MT CO<sub>2</sub> / year</b>
<b>Estimated Carbon equivalent</b>	<b>1,780,229 kg Carbon/year</b>	<b>Estimated Carbon equivalent</b>	<b>1,132,606 kg Carbon/year</b>
	<b>1,958 MT Carbon/year</b>		<b>1,246 MT Carbon/year</b>
		<b>Net Estimated Annual Savings</b>	<b>2,612 MT CO<sub>2</sub> / year</b>
			<b>712 MT Carbon/year</b>

**VOCGEN CHP Project Feasibility  
Maintenance Schedule**



**Expanded Foam Manufacturing Company**

Prices:	US Energy Information Agency - Energy Prices for June, 2013	
	Quarterly Service	\$6,000.00
	Minor ASE8 engine rebuild	\$70,000.00
	Major ASE8 engine rebuild	\$85,000.00

		<b>Total</b>
Year 1	Quarterly Service	(\$24,000.00)
Year 2	Quarterly Service	(\$24,000.00)
Year 3	Quarterly Service and minor rebuild	(\$94,000.00)
Year 4	Quarterly Service	(\$24,000.00)
Year 5	Quarterly Service	(\$24,000.00)
Year 6	Quarterly Service and major rebuild	(\$109,000.00)
Year 7	Quarterly Service	(\$24,000.00)
Year 8	Quarterly Service	(\$24,000.00)
Year 9	Quarterly Service and minor rebuild	(\$94,000.00)
Year 10	Quarterly Service	(\$24,000.00)
Year 11	Quarterly Service	(\$24,000.00)
Year 12	Quarterly Service and major rebuild	(\$109,000.00)
Year 13	Quarterly Service	(\$24,000.00)
Year 14	Quarterly Service	(\$24,000.00)
Year 15	Quarterly Service and minor rebuild	(\$94,000.00)
Year 16	Quarterly Service	(\$24,000.00)
Year 17	Quarterly Service	(\$24,000.00)
Year 18	Quarterly Service and major rebuild	(\$109,000.00)
Year 19	Quarterly Service	(\$24,000.00)
Year 20	Quarterly Service	(\$24,000.00)
	<b>Total over 20-years</b>	<b>(\$945,000.00)</b>
	Yearly cost	(\$47,250.00)
	Monthly cost	(\$3,937.50)

**Assumptions and Notes**

	Energy			Maintenance (k\$)	Annual O&M (\$k)	Capital (k\$)	Annual CO2 Emissions (MT)	Annual Carbon Emissions (MT)
	Gas (k\$)	Electric (k\$)	Credit (k\$)					
Thermal Oxidizer ( <i>TO</i> )	(\$388)	(\$95)	\$16	(\$25)	(\$602)	(\$2,275)	7,180	1,958
TO Heat Recovery ( <i>HR</i> )								
VOCGEN Gas Turbine Oxidizer ( <i>GTO</i> )	(\$406)	\$0	\$889	(\$47)	\$436	(\$3,490)	4,568	1,246
GTO Heat Recovery ( <i>HR</i> )								

**Volatile Organic Compound: Pentane**

<b>Total</b>	1,045,440 VOC lbs/year	50,000 CFM Airflow Total
<b>Drying Exhaust Pentane</b>	10-100 lbs/hr	5,000 CFM voc laden air from production plant and voc concentrator
		1,200 CFM ambient air flow
Process air temp	75-100 deg F	
<b>Destruct Removal Efficiency (DRE) Requirement</b>		BACT
<b>VOCGEN Gas Turbine Oxidizer (GTO)</b>	ASE 8 Gas Turbine VOC	6,200 cfm inlet air at 75°F
<b>GTO Recoverable Heat</b>	60°F inlet air Temp	Exhaust Gas Heat Content ≈6.22 MMBtu/Hr waste heat (<1000°F) for steam; fired to approx. 1300F
<b>Natural Gas Fuel</b>	20,100 Btu/lb Lower Heating Value	
<b>Radiated heat:</b>	"radiated, conducted and convected" from the engine at continuous duty - 180,000 Btu/hr	

The amount of natural gas required to run the gas turbine is dependent on two process variables: 1) the load placed on the gas engine (kW demand), and 2) the energy content supplied by the VOC laden air stream.

The system's main function is to convert the energy provided primarily from a natural gas supply (and to a lesser extent, the energy provided by a volatile organic compound laden air stream) to produce 525 kW of electrical power at 480 VAC, three-phase, 60 Hz, destroy VOC waste streams, as well as produce approximately 6 MMBTU" recoverable heat. Inlet air combined with a concentration of a volatile organic compound (at a level below 50 % LEL), will be drawn in, compressed and heated in a secondary combustion chamber, then introduced into a primary combustion chamber with natural gas to fuel a combustion process which operates the gas turbine at a speed of 41,730 rpm. The mechanical rotation of the gas turbine drives an AC generator at a rate of 1,800 rpm via a gearbox.

**Maintenance Schedule:** Service checkup including replacing belts, filters and other consumables is required quarterly. Minor rebuild of the ASE8 engine every 2.5 years and major rebuild of the engine every 3 years.