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FINAL REPORT

RFP 02 – R01-G11

AIR POLLUTION EMISSION REDUCTION

Design and Build Vortex Pre-Combustion and Combustion Chamber

Submitted by

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To

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Date:	September 24, 2003

FINAL REPORT
RFP 02 – R01-G11
AIR POLLUTION EMISSION REDUCTION
Design and Build Vortex Pre-Combustion and Combustion Chamber

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Executive Summary

a. Acknowledgement of TCET funding

General Vortex Energy, Inc. gratefully recognize the significant assistance that the Texas Council on Environmental Technology provided through this grant. The funding has allowed GVE to move forward significantly toward the development of the complete Jirnov Vortex Engine. The experiments to date establish that the technology is sound and that the Jirnov Vortex Engine can meet a thermal efficiency of at least 60% as compared to a diesel engine at 45%, a natural gas turbine at 30%, and gasoline engine at 30%, in addition, the JVE has advantage of significant emissions reductions.

A result of the funding is that the US Naval Research has extended a grant to use the technology developed in a hybrid JVE Turbine/Fuel Cell power plant under the STTR program, phase I with a very strong possibility of going to Phase II.

b. Summary of Project

General Vortex Energy, Inc (GVE), a Texas-based corporation, was formed to develop and market four patent-protected technologies that, when combined into a single energy production unit, greatly increase fuel efficiencies while reducing the emission of harmful gases like $NO_x \equiv (NO+NO_2)$, carbon monoxide, and carbon dioxide. The final product, the Jirnov Vortex Turbine (JVT), will revolutionize the ways in which power is produced.

The JVT is a suitable replacement for most internal combustion engines and gas turbines, currently a $265 billion a year market. The company anticipates earning royalties from licensing agreements and revenues from the sale of Jirnov Vortex Turbines.

The Opportunity

GVE will initially target three specific market segments: distributed power generation, inlet air chillers for gas turbines used by utilities to generate electricity, and marine power and propulsion units. These three markets segments represent over $20 billion in annual sales for the next 5 to 7 years. The Jirnov Vortex Turbine technology will permit GVE to expand into other market segments, including pumping, refrigeration, and engines used in commercial aviation, heavy earth-moving equipment, and even automobiles.

Prototypes and Customers

GVE has completed the design and fabrication stages of the four patented components of the Jirnov Vortex Turbine. Fuel efficiency testing and exhaust emissions testing are currently underway in the company's R&D facility with the JVT test stand, see Figure 1. The results of the testing will be verified and certified by a reputable third party. GVE is currently negotiating a license agreement with a major manufacturer to commercialize the company's technology in the turbine inlet air cooling market.

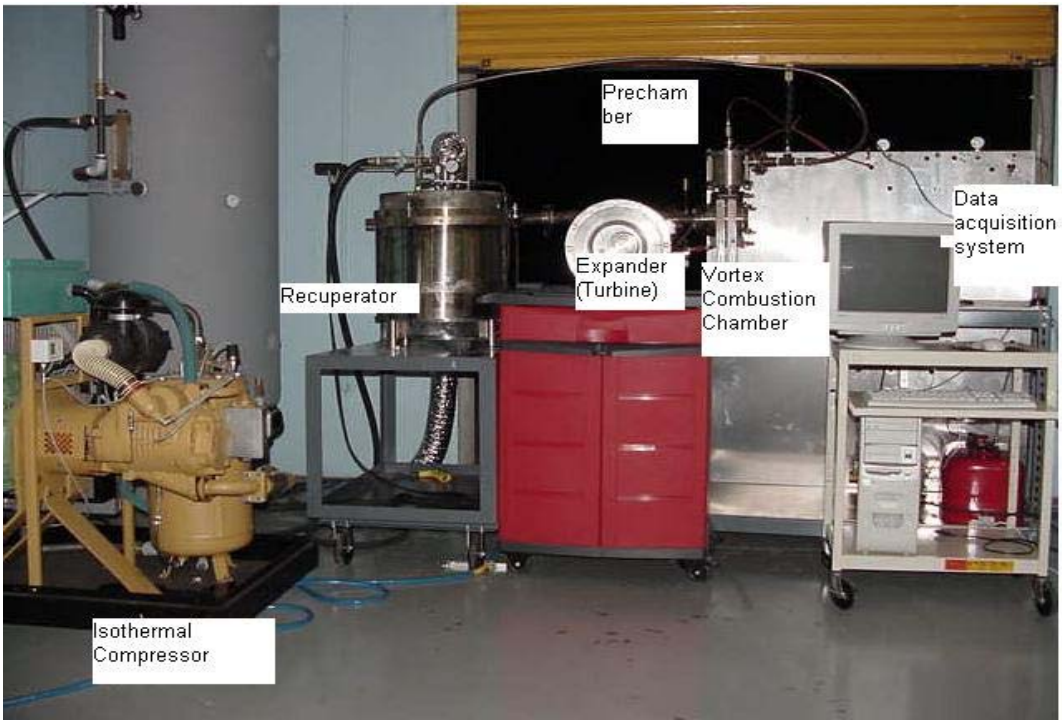


Figure 1. The JVT Test Stand.

The GVE Solution – the Jirnov Vortex Turbine

The four patent-protected technologies used in the JVT consist of:

1. A Sliding-Vane, Isothermal Compressor.
2. A Vortex Recuperator / Heat Exchanger.
3. A Vortex Combustion Chamber.
4. A Sliding-Vane Expander.

The R&D team at GVE redesigned each part to be "State-of-the Art." Used alone, each component represents a significant improvement in design and efficiency; combined, the technologies result in a super efficient device for power generation. Compared to currently available gas turbine technology, the JVT will consume only 55% of the fuel while delivering the same amount of power. CO2 (the greenhouse gas) is reduced by 45%, while the major component of smog, (NO_x) is reduced by almost 80%. The inherently simple design and materials used in the JVT reduce both the manufacturing and maintenance costs. High fuel efficiency, low emission of pollutants, quiet operation, and lower costs will speed the adoption of the JVT in the marketplace.

A Vortex Combustion Chamber

The goal and objective of the work funded by TCET was to build a prototype of a pre-combustion chamber and a combustion chamber together to enable the complete assembly and testing of the Jirnov Vortex Engine as more fully described in patent no. 5,839,270. The combustion chamber constitutes one of four components of the JVE. The combustion chamber device utilizes a vortex mixing of fuel and air to achieve near complete combustion at controlled temperatures so as to improve combustion efficiency, reduce NOX and CO emissions, and reduce unburned hydrocarbons. The combustion chamber met the expectations and performance criteria initially promised in the grant proposal.

Preliminary testing began on the Vortex Combustion Chamber with testing of the fuel injector for the fuel dispersion and the initial results were impressive. The continuous combustion within the combustion chamber was very stable, even with a very lean fuel mixture. Very low NO_x and CO emissions were generated. The combustion chamber operated very quietly. *(HISTORY: This combustion chamber is similar to one designed by Dr. Jirnov to burn aluminum as the fuel. It is currently used for propulsion of a super-cavitating, super-fast torpedo (240mph) for the Russian Navy).* Initially, only the pre-combustion chamber was fired and checked for proper operation. It worked perfectly, and it properly prepared the liquid fuel (in this case, jet fuel) for final combustion. During the very first experiments the emissions were analyzed. Readings inside the combustion chamber (before equilibrium) for NO_x measured 26 ppm for jet fuel (see Appendices). The entire engine (excluding the Expander): Isothermal Compressor, Recuperator and Vortex Combustion Chamber *was* using kerosene as the fuel. The Recuperator gave up the exhaust heat to the compressed air so the exhaust gas temperature is very low. The average NO_x was about 45 PPM without any water or ammonia injection to reduce it! More impressive the NO_x reduction was obtain with the methanol as the fuel. NO_x emission was less than 25 PPM.

The combustion chamber is where the continuous combustion of the fuel and air mixture occurs at constant pressure to raise the temperature. The fuel can be virtually any hydrocarbon, alcohol, gaseous or liquid. The fuel, if liquid, is atomized through the nozzle into the pre-combustion chamber, is pre-ignited and then expelled into the vortex combustion chamber. It is in the vortex combustion chamber that the high-pressure, high velocity air is mixed with fuel and complete combustion then occurs. The vortex combustion chamber operates at a relatively low bulk temperature (1300°K or 1880.33^{o}F) because of the large amount of air that is input (lean mixture). This temperature is well below the temperature of NO_x formation (1700K). Because the air (Oxygen) to fuel ratio is very high and vortex flow creates a homogeneous mixture, the fuel is completely burned, leaving little or no CO in the exhaust. The fuel gives up its heat energy and the combustion gases expand at constant pressure.

General Vortex is ready to license the combustion chamber for several applications including as a flare stack combustor, a source of heat in commercial kitchens, ceramic and brick operations, and as a heat source for standard turbine engines. The combustion chamber has considerable potential using bio-fuels, alcohol and waste hydrocarbons.

II Introduction and Background

i. Why is the technology important?

Power Generation in the 21st Century

Each year, the users in the U.S. alone spend over $100 billion on various types of engines to produce power – electrical, mechanical, and thermal. Despite technological advances, most all of these power generation systems have only been fine-tuned: the engine efficiencies may have been improved slightly, but the underlying thermodynamic principles have not been modified to effect a drastic improvement. The result is that most engines in service today suffer from two major problems: low fuel efficiency and emission of high levels of polluting gases in the exhaust gases.

Problems with Current Technologies

While the world economy depends on fossil fuel-driven engines for the production of power, several trends are magnifying the importance of the problems of low efficiency and high pollution. First, a significant fraction of the fossil fuels resides in politically unstable countries. Recent experiences with changes in the Venezuelan government and the Second Gulf War demonstrate how the volatility of fuel prices can be adversely affected by global politics. Most everyone understands that oil producers suffer at the hands of volatility, but consumers are harmed as well as the costs associated with fluctuating fuel prices are pushed down the value chain to the end-user. This volatility will only continue.

Second, the regulatory environment is forcing companies to reduce the noxious gases emitted when fuels are burned. The Environmental Protection Agency (EPA) and its rules are leading the effort to reduce air pollution. To avoid scrapping the significant investments in older plants, these facilities are retrofitted with expensive scrubbers. New facilities tend to burn cleaner fuel such as natural gas rather than the coal that fires most electricity-generating plants. The rate at which the EPA wishes to reduce pollutant emissions demands the development of new power production technologies. The Kyoto Protocol emphasizes that this same regulatory trend is even stronger on a global basis. Everyone, from the large, central station power plants run by major public utilities to the average consumer driving a car can benefit financially from advances in power technology. Fuel is the largest contributor to variable costs in turbines and engines. Reducing fuel consumption while generating the same amount of power leads to an immediate economic benefit; the less fuel consumed the greater the savings. Likewise, “cleaner” power that does not need scrubbers or catalytic converters to treat exhausts creates additional cost savings by eliminating extra materials, maintenance, and engineering complexity.

Background of the Jirnov Vortex Turbine/Engine.

For the generation of electrical energy by use of heat engines, the primary (chemical) energy must be converted several times: Chemical energy → heat energy → mechanical energy → electrical energy. Each conversion causes losses, but particularly critical is the step from heat energy to mechanical energy, which is the function of the heat engine. Carnot (1796-1832) described the best possible heat engine cycle. The Carnot cycle is based upon a cyclic process of adiabatic compression with heat input at a higher temperature level (T3) see Fig.2, adiabatic expansion with heat removal at a lower temperature level (T1) and adiabatic compression again. The maximum efficiency η obtainable in this cyclic process is the ratio of the mechanical energy gained to the heat energy originally employed. It may be expressed in terms of the temperatures T1 and T2: $\eta = (T3 - T1) / T3$.

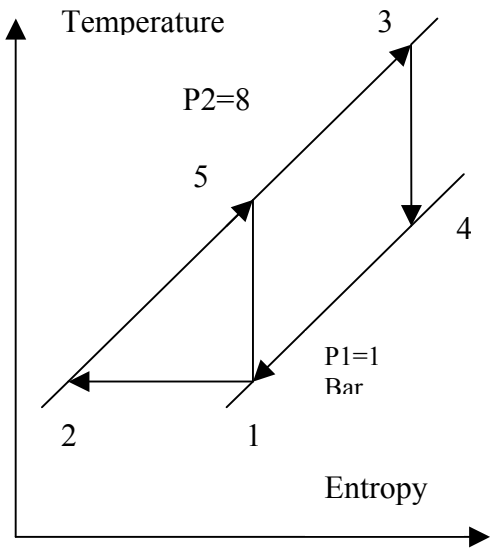


Figure 2. T – S diagram of modified Brayton cycle.

The Carnot cycle is based upon the assumption that the medium in the engine is an ideal gas and the whole cycle is reversible. In practice, these conditions are not fulfilled and none of the steps are pure Carnot processes. The efficiency stated above thus remains the theoretical maximum from a heat engine. The current state of propulsion engines or distributed generation technologies using heat engines shows an average efficiency of between 20% and 40%. These low efficiencies in a high-cost energy market indicate a great need for more efficient technologies**.**

Thermodynamic cycle and hardware parts of the JVT.

This project proposed a new method of achieving a very high efficiency, namely, optimizing every stage of the thermodynamic process, a modified Brayton cycle (Fig.2). The order of processes in the thermodynamic cycle is 1-2-5-3-4-1. It is known, that isothermal compression is most efficient in compare with adiabatic or polytrophic compression. The increase in efficiency due to nearly isothermal compression is approaching to 15%. Another increase of the efficiency is due to regeneration of exhaust gas energy. The increase in JVT efficiency due to recuperation is approaching 20%. Thus, this two modified processes add about 30% efficiency to the conventional Brayton cycle, making the modified Brayton cycle about 60% efficiency.

The cycle begins with the ability to utilize an isothermal compression process, removing the heat from the compressed air by water injection. Isothermal compression is not possible with the conventional gas turbine because the water would ablate the compressor rotor blades because of the very high rotary speeds. By utilizing a sliding vane compressor, with a revolutionary vortex combustion chamber and a vortex recuperator, high levels of efficiency with low emissions and noise are possible.

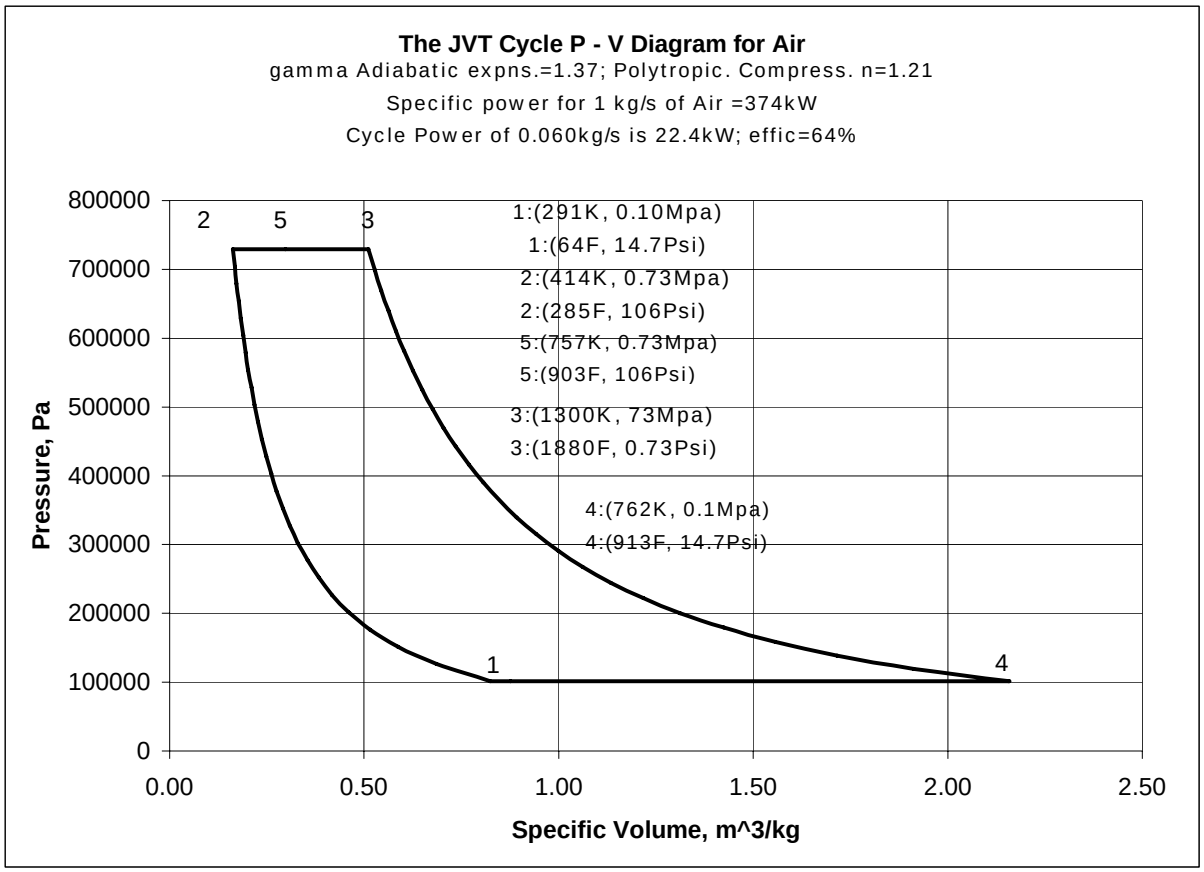


Figure 3. P – V diagram for the JVT.

Process 1-2 (*process numbers refer to T-S* Fig. 2 *and P-V diagrams* Fig. 3) of the cycle is accomplished in the isothermal sliding vane compressor, see Fig.4. The near-isothermal compression of the air that is accomplished by injecting atomized water into the air at all stages of the compression cycle. The water absorbs the heat generated by the compression, leaving the air cool (air temperature rise only 10°C). By keeping the air cool during the compression process, less work has to be expended to achieve the increase in pressure. The hot water is extracted from the compressed air in a vortex separator, and used in the absorption refrigeration cycle. The GVE Inc. water-injected Isothermal Compressor has been designed and is ready to fabricate. However, to

expedite the project, GVE purchased an off- the-shelf isothermal compressor that is slightly less efficient than GVE's own design, but adequate for the prototype. The Isothermal Compressor has been tested. The calculated efficiency was 15% greater than a conventional gas turbine compressor.

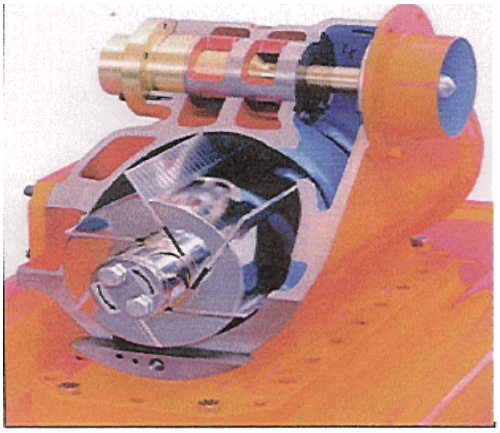


Figure 4. Isothermal sliding vane compressor.

Process 2-5 is accomplished in the vortex recuperator, see Fig.5. This is the preheating of the compressed combustion air by the hot exhaust in the vortex recuperator Process 4-1. This device takes hot exhaust gas exiting of the expander and exchanges its heat with the compressed air coming from the isothermal compressor. This adds energy to the compressed air prior to its entry into the vortex combustion chamber. The increase in JVT efficiency due to recuperation is approaching 20%.

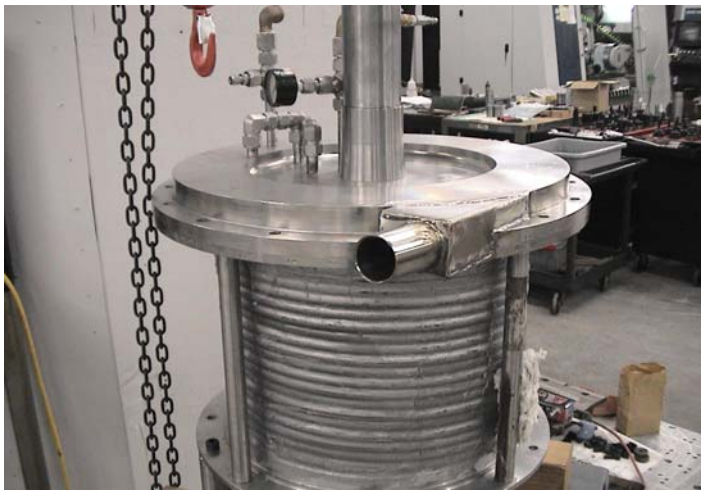


Figure 5. The Recuperator.

The temperature of exhaust gases from recuperator is slightly higher then ambient. In addition to its high efficiency, this unit requires 1/3 of the metal to fabricate and, more importantly, is 1/3 the size of conventional heat transfer units with the same heat flux. This result was achieved by using intensive vortex flow inside the heat exchanger channels, dramatically increasing the heat transfer. The Vortex Heat Exchanger is designed and has been tested to work at the high exhaust temperature (up to 930°C) and the high inlet air pressure (150 Psi) from the compressor. The recuperator has a design efficiency of 95%. The Vortex Heat Exchanger is a separate product and could be sold for use by many different industries. Because of its small size and high heat transfer rates, the U.S. Navy expressed the interest in testing a unit for possible use in the fleet.

Process 5-3 is accomplished in the vortex combustion chamber, see Fig. 6.

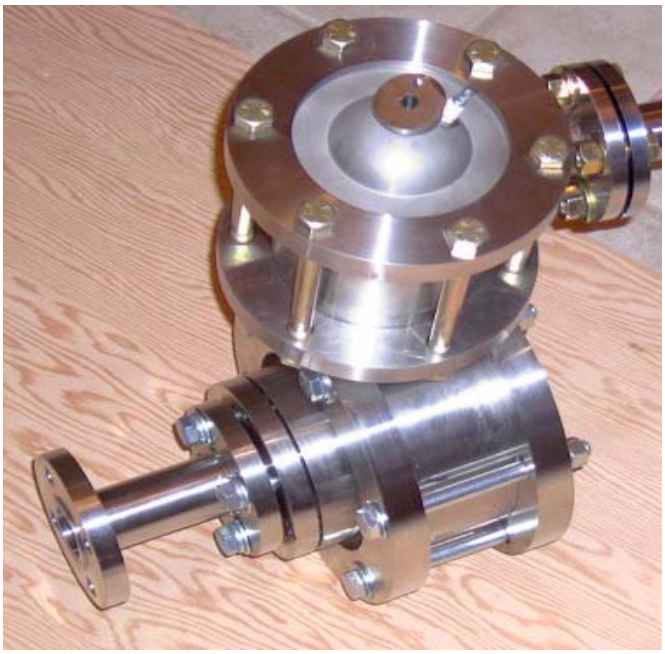
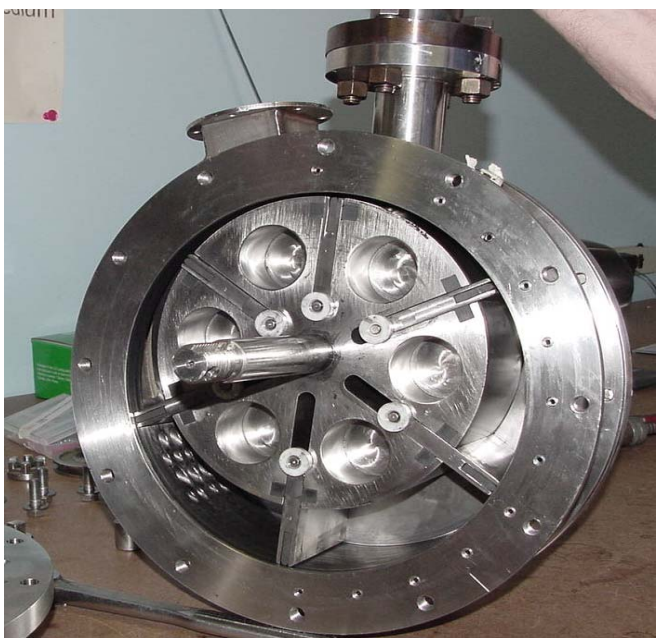


Figure 6. Pre-chamber and Vortex Combustion Chamber (bottom).

This is where the continuous combustion of the fuel/air mixture at constant pressure occurs to raise the temperature. The fuel can be virtually any hydrocarbon, gaseous or liquid. The fuel, if liquid, is atomized through the nozzle Fig.6, into the pre-combustion chamber, pre-ignited and then expelled into the vortex combustion chamber. It is in the vortex combustion chamber that the high-pressure, high velocity air is mixed with fuel and complete combustion occurs. The vortex combustion chamber operates at a relatively low bulk temperature (1300°K) because of the large amount of air that is input (lean mixture). This temperature is well below the temperature of NO_X formation (1700K). Because the ratio of air (Oxygen) to fuel is very high and

vortex flow creates a homogeneous mixture, the fuel is completely burned, leaving little or no CO in the exhaust. The fuel gives up its heat energy and the combustion gases expand at constant pressure.

Process 3-4 is accomplished in the sliding vane expander, see Fig.7. This process is the expansion of the hot gas through the expander (turbine) to produce work, lowering both the temperature and pressure of the working gas. The expander is the fourth major component of the engine. In the expander, the gas forces (pressure) act perpendicular to the sliding vanes at all times, producing only rotary motion. The force acting on the sliding vanes produce a much greater torque than the force acting on a gas turbine blade for the same parameters of flow. This provides high torque at low rpm, a tremendous advantage for the JVT over conventional gas turbines. Also, the torque curve of the JVT is nearly flat, barely dependent upon the rotary speed. Exhaust gases are vented through the recuperator to give up excess heat to the compressed inlet air, prior to that incoming air entering the combustion chamber (Process 4 –1).



The High-Temperature, Sliding-Vane Expander represents the greatest technological challenge to the GVE Team. The problems are not overly difficult; they just require a very structured, methodical approach.

Figure 7. Sliding vane expander.

The expander has taken more time to complete than originally budgeted, but much of the timeline slip was from being ultraconservative in the fabrication. For instance, the stainless steel used in the fabrication (Haynes) has a 6 to 8 week delivery schedule for billets. To preserve this material, most parts were first made from aluminum, and completely tested before machining the stainless steel. The expander fabricated with the aluminum rotor has been tested at 1800 rpm for 24 hours, which demonstrated no kinematic problems with the design. The results were as expected and no problems were encountered. The Expander testing started in June, 2003. The expander is the final component needed for assembling a complete Jirnov Vortex Turbine. After testing the expander, the JVT will be assembled and extensively tested. It is anticipated that the efficiency claims made regarding the JVT will be experimentally proven prior to early 2004!

ii. Environmental Benefits that Can Be Expected.

The Example of calculation's comparing fuel consumption of JVT and typical gas turbines.

The following compares turbines of 1000KW, working 6000 hours (approx. one year), powered by different engines, one the Jirnov Vortex Turbine (JVT) and the other a standard gas turbine burning natural gas with calorimetric heat 1000 BTU/cu ft.

Energy Benefits.

The calculated JVT efficiency, including losses, is over 60%. The efficiency of a standard gas turbine, even with recuperation, is about half that. A 1000KW generator powered by a standard gas turbine for 6000 hours (one year) will consume 73 million cubic feet of natural gas; the same generator powered with the JVT Turbine/Engine would use only 33 million cubic feet of natural gas. This is more than a 50% improvement in energy efficiency.

Fuel Benefits.

Fuel consumption for the proposed JVT: The JVT thermodynamic cycle consists of near "isothermal" compression (polytropic index 1.21), heat addition, adiabatic expansion (index 1.37) and recuperation of air from temperature T2 to T5. The JVE efficiency corresponding to the cycle is:

$$JVE_{eff}=\{T3*E_{exp}*[1-1/P_r\text{^}n]-T1/E_{comp}*n_p*\ln(P_r)\}/(T3-T5)$$

Where $T5 = E_{rec}*\{T3*[1-E_{exp}*(1-1/P_r\text{^}n)]-T2\}+T2$

This formula takes into account <u>maximum</u> losses in the compressor, expander, recuperator and pressure losses within the Turbine/Engine. The initial data for the air is: $n=(\kappa-1)/\kappa=0.27$ (isentropic expansion) and $n_p=0.174$ (polytropic compression-almost "isothermal"), considering C_p of air equal to C_p of mixture and $T1=292^oK$. Assume the total pressure losses are 10% and the compression ratio is 8, so the $P_r=8*0.9=7.2$. Assume the expander efficiency, $E_{exp}=0.85$, the compressor efficiency, $E_{comp}=0.85$, and the recuperator efficiency, $E_{rec}=0.9$, the working parameters of the JVT were calculated as: $T2=411.3^oK$, $T5=757^oK$, $T3=1300^oK$, $T4=763^oK$.

Thus for the fixed chosen parameters the JVE efficiency exceed 60%.

It is important to emphasize that the working parameters of the JVE are within the range of the working parameters of a conventional gas turbine. Consequently, the design of JVE does not require exotic materials for its construction. Note that the Carnot cycle efficiency for the same temperature range is 77.6%. The JVE efficiency approaches, but of course, does not exceed the Carnot cycle efficiency.

The fuel consumption for the JVT in (ft^3/Year/Unit), for 6000 operating hours is:

1,000,000(Joule/sec)/[1050(Joule/Btu)]*3600(sec/hr)*6000(hr/yr)/1000(Btu/ft^3)/0.62 =3.31*E+7 ft^3/yr

The fuel consumption for a comparable gas turbine unit in (ft^3/Year/Unit):

For a gas turbine with power less than 100MW, co-generation is usually not used for economic reasons. With this assumption, the efficiency of gas turbines equals 28% (average from different literature data) and assuming 6000 operating hours per year, the fuel consumption would be:

1,000,000(Joule/sec)/[1050(Joule/Btu)]*3600(sec/hr)*6000(hr/yr)/1000(Btu/ft^3)/0.28= 7.35*E+7 ft^3/yr.

Thus, the proposed JVT engine would use only 45% of the fuel required for a simple cycle gas turbine to produce the same amount of power! The JVT also produces only 45% of the CO_2 as the gas turbine! The fuel saved in a single years is 4.04*1E+7 ft^3 of natural gas per one megawatt unit. The technology of the JVT provides more than a 50% improvement in fuel (energy) efficiency over current gas turbine power generation technology while greatly reducing emissions!

General Vortex Energy Inc. is currently in the process of lining the Expander/Turbine and Vortex Combustion Chamber with ceramic materials. With a ceramic expander and combustion chamber, the working temperature of the JVT can be increased to 1700°K, resulting in an efficiency approaching 70% and even more dramatic fuel savings. The NOX still will be lower than for conventional gas turbine.

Similar fuel savings occur if the JVE is compared to the internal combustion engine. When compared to the diesel engine, the JVT will consume only 70% of the fuel of a diesel engine.

A gas turbine cannot use "isothermal" compression by injecting water, like the JVT, because the very high rpm of the turbine (>25,000 rpm) and high velocity of the gases would cause significant turbine blade erosion and result in catastrophic failure. The JVT operates at very low rpm (1500-2000) and the injection of water during the compression cycle removes heat from the air being compressed, producing near isothermal compression. The water will also help to lubricate and cool the sliding vanes. Isothermal compression adds 15% additional thermal efficiency to the JVT when compared to a gas turbine operating on the standard Brayton Cycle. Also, the Vortex Recuperator is more efficient than current products (even if compared to co-generation) and adds another 15-20% to the efficiency of the JVE. The Vortex Recuperator does not require the additional water loop and steam turbine like a co-generation unit. This simplifies a power plant design utilizing the JVT and greatly reduces the cost of a power generation unit.

Economic and environmental benefits.

The JVT propulsion engine has application over a wide range of power applications and has tremendous advantages over current power systems, be they diesel, gas engines or gas turbines. This is because each component of the JVT has been optimized for thermodynamic cycle efficiency. The low weight-to-power ratio, low temperature operation, all rotary motion, low noise, reduced NO_X and other emissions and extreme thermal efficiency are found in no other known engine or hybrid system design. Its ability to burn any gaseous or liquid fuel only adds to the Non-Fuel Cell JVT propulsion engine versatility.

For the same amount of produced energy, the JVT produces only 22% of the NO_X, 22% of the CO and 45% of the CO_2 that the best gas turbine engines produced today. In addition, the JVT uses only 45% of the fuel volume of the gas turbine for the same power output.

iii. The commercialization plan and penetration potential of the technology and estimated emissions reduction.

General Vortex Energy, Inc. is pursuing further development of the Jirnov Vortex Turbine through additional funding under an STTR Grant with the U.S. Naval Research. The focus is refining the design and improving the operation, an additional step before introduction of a full marketing plan with the engine. In the interim, General Vortex Energy, Inc., is developing a marketing plan specifically focused on the marketing of the Combustion Chamber. We are actively seeking licensees. As can be seen by the examples of environmental benefits described above, fuel consumption alone--if the engine and/or combustion chamber were to replace current engines and combustion devices--the result would be nearly ½ as much as conventional engines, with a resultant ½ reduction in the carbon dioxide and major reduction of the carbon monoxide and nitrous oxides.

Target Markets for the Jirnov Vortex Turbine.

The annual worldwide market for engines is remarkably large – over $265 billion in 2001. The size of the market is an indication of the important role that engines play in our economy: power plants, back-up generators, pumps, boats, airplanes, and cars all contain engines of some sort. General Vortex is a startup, and as such, must prioritize its target markets. Management will first introduce the JVT to the three target sectors where the engine's value will be most easily recognized and the technology accepted:

- Power generation
- Marine propulsion and power
- Pumping and compression in pipelines

The Market for New Power Generation Capacity

The world's demand for reliable electric power will only increase in the future. The Digital Age means that computers and other electronic appliances are ubiquitous and on continuously, creating an insatiable appetite for electricity. The fragile nature of electronics requires high quality, reliable power with few or no voltage spikes or power outages. The new technologies and industries rely on the availability of high quality power in an incredible way; internet-based operations, for example, do not wish to experience more than a few seconds of power loss during an entire year, regardless of the reason. Thus, while the utilities continue to add electricity generation capacity to the grid, individual businesses explore ways in which to decrease dependency on the utilities. Unfortunately, the supply cannot always keep up with the demand, as evidenced by rolling brownouts in California in recent summers. The Energy Information Administration (EIA) of the U.S. Department of Energy forecasts that residential power consumption will increase by 27% and industrial power consumption will increase by 36% by the year 2025. The EIA also believes that new generation capacity will be added at the rate of 10 to 20 gigawatts a year for the next 20 years (Figure 3). Most of this new capacity will be based on natural gas turbines rather than the traditional coal-fired plants. The U.S. demand for electricity, while growing, is also changing.

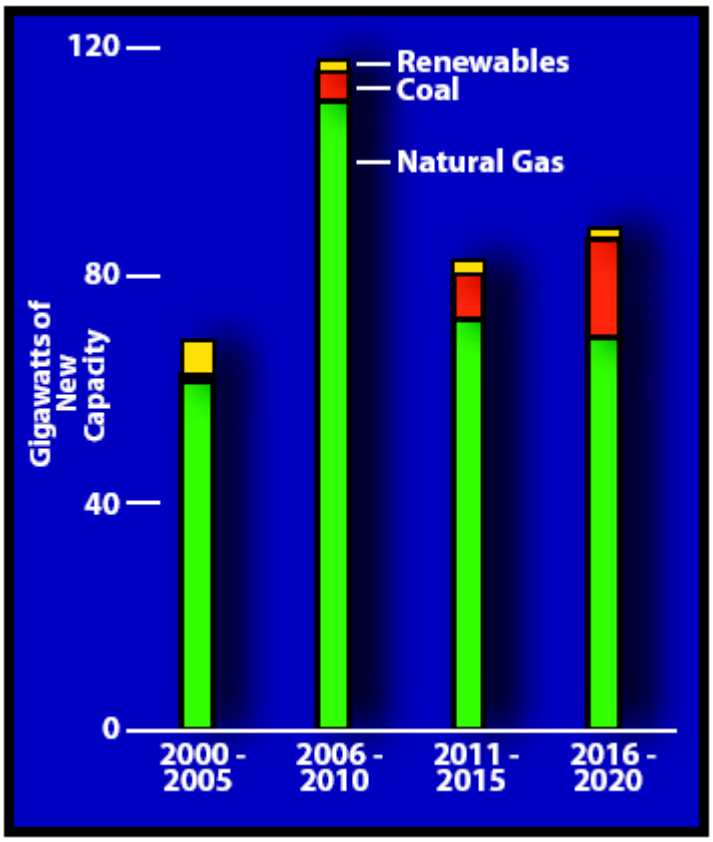


Figure 8. New Generation Capacity. Forecasts for new generation capacity over the next 2 decades. Includes all production methods.

The JVT will be highly competitive with the traditional gas turbine in large power plants. Even if the capital costs were identical, the increase in fuel efficiency alone makes a convincing argument for using the JVT. Although new facilities will be built in the future see Fig. 8, the U.S. currently has an adequate supply of generation capacity; the problem is the grid – the transmission and distribution system composed of high voltage power lines crisscrossing the nation. The loss of power in electrical distribution is huge, leading to the desirability of on-site power generation. The loss of power in distribution has spurred developed nations to reevaluate policies that allow huge power generation plants and distribution lines to be built. The relatively small size, fuel efficiency, and quiet operation of the JVT will make it a perfect fit for the Distributed Generation market. Additionally, significant health hazards are attributed to the electro-magnetic radiation (EMR) that high voltage electric lines emit. Suspected health problems caused by EMR include immune system diseases and tumors, including cancer. The electrical generation industry is very interested in a solution like the JVT that could be installed in every substation for local power generation, eliminating the need for high-voltage electric distribution lines.

Distributed Generation

Distributed generation (DG) refers to the production of electricity outside of a centralized power generation facility like those managed by big utilities. The production capacity can exist on either side of the meter (either the utility owns the production capacity, or the utility customer owns the production capacity). DG is typically broken down into several market segments:

• **Power Only** – cost-effective for users in areas with high electric price rates or for users who require high quality (99.999% up-time) power

• **Combined Heat and Power (CHP)** – cost-effective for locations that can use excess thermal energy for water heating or manufacturing processes

• **Peaking Power** – reduces a facility's power demand during high-priced periods such as the summer months when overall demand and price escalates

• **Remote Power** – an effective means of providing power to a site that is not on or near a utility grid (remote oil and natural gas wellheads, off-shore drilling platforms, etc.)

• **Back-up Power** – emergency power generation systems like those found at hospitals and many other critical facilities

• **Generation of Power from Waste Gases** – microturbines can use low-quality methane fuel sources such as landfill gases and digester gases from water treatment plants to fill a facility's electricity and heating needs. The installed DG capacity at non-utility locations is currently 20 GW; this base is expected to grow to 300 GW by 2011, an annual market of approximately $5.6 billion. The market can be served by a variety of technologies, including JVT-based microturbines, traditional microturbines, diesel generators, fuel cells, wind, and solar power. Some technologies are appropriate for only a limited number of DG uses; in contrast, a JVT-based microturbine could serve all the DG market segments.

Marine Propulsion and Power

Marine gas turbines were a $400 million market in 2001, a 33% increase from the previous year. Many gas turbines and diesel engines are used to propel vessels of all sizes. Gas turbines have been used in a few high-speed container ships, but the rapid increase in fuel prices has led many of these ship owners to replace the turbines with diesel engines. The converted ships suffered a major loss in both speed and cargo capacity. Gas turbines remain in heavy use in naval vessels where the cost of operation is not a primary concern. The high torque/low rpm design and the high power to weight ratio of the JVT create vast new markets in the marine industry, places where gas turbines are not currently in use. Its ability to be manufactured inexpensively in small horsepower versions (25 to 1000 hp) means that the JVT can be used in yachts, fishing vessels, pleasure craft, and crew boats that are currently dependent upon internal combustion engines. The lack of vibration and quiet operation are JVT features demanded by all vessel owners, but are required for military vessels that need to operate quietly to avoid detection by the enemy. Gas turbines and diesel engines cannot operate as quietly as the JVT. The JVT can use "bunkers," the cheapest form of fuel available and the lowest quality of liquids produced

from the fractionation of crude oil. Many ships are currently configured to use bunker fuel, making a retrofit with the JVT reasonably simple. The design advantages of the JVT over gas turbines will permit the JVT to be used in a broader range of marine applications, expanding the market size from its 2001 level of $400 million. The marine propulsion market for all engine types is expected to range from $4.5 to $5.5 billion for the next four to five years.

Pumping and Compression in Pipelines.

In 2001, the value of mechanical drive gas turbines used in pumping applications was $700 million, up 40% from the previous year. Pipelines for natural gas, petroleum, and other materials use gas turbines, diesel engine, and large-bore gas engines to move the products through the pipelines. Pumping stations may be placed about 150 kilometers apart, with the prime movers at each station ranging in size from 5 to 20 MW (the distance between stations and the size of the pumps depends on terrain). Gas turbines and large-bore gas engines can use the fluid being pumped as fuel, but many pumping stations are in remote locations and, if powered by diesel engines, require frequent refueling. Pipeline compression consumes 7 to 10% of the throughput as fuel. In recent years, the value of natural gas has increased dramatically, leading to a great demand for high efficiency power sources. A major pipeline might have as much as 1000 MW of installed power, resulting in fuel bills comparable to those of a medium-sized airline! The EPA and other government agencies are aware of the amount of fuel consumed by pipelines and are now closely monitoring the amount of pollution emitted into the atmosphere by pipeline companies. The JVT, because of its high efficiency, low emissions, and fuel flexibility, is an excellent choice for pipeline compression.

Other Market Opportunities

The Jirnov Vortex Turbine and its component parts have a wide variety of applications outside of those markets listed above, including:

- Renewable energy
- Refrigeration in remote areas or for food, fish, and dairy processing
- Chillers / air conditioning
- Military vehicles
- Buses used in metropolitan settings

Three of the key markets are discussed below.

Renewable Energy.

The fuel flexibility of the JVT makes it ideal for use with biofuels such as ethanol and vegetable oils made from corn and soybeans. Renewable energy comes from municipal sources, too. Both landfill sites and municipal water treatment facilities produce substantial amounts of methane gas from the degradation of organic matter on-site. Although this methane is typically of lower grade than natural gas, it will work well to power the JVT, which in turn, could provide enough electricity to run the facility with essentially “free” fuel.

Refrigeration and Chillers.

The GVE Recuperator (heat exchanger) is one of the components of the JVT that has its own market (apart from the entire JVT). This recuperator is 1/3 the weight and volume of its competitors, yet it is just as efficient. Although its small size and weight make it ideally suited for applications where space and weight need to be minimized, it should compete effectively throughout the marketplace: the reduction in materials and size means that the GVE recuperator can enter the market at a significant price advantage if needed. Potential customers include HVAC, refrigeration/AC engineering and contractor companies, as well as the entire U.S. Navy and Marine fleets that are currently powered by steam. The Navy and Marine fleets, in particular, would gain a great deal of needed space inside the engine rooms of their vessels.

Buses and Transportation.

Recently, Advanced Vehicle Systems, Inc. (**http://www.avsbus.com/**) has developed a hybrid bus that uses a Capstone microturbine to generate electricity to power the bus. While the JVT could fill a similar role, the design could be greatly simplified. Traditional gas turbines must operate at very high rotational speeds, even while the engine idles; the turbine consumes fuel at about the same rate all the time. As noted for railroad, trucking, and marine propulsion, the high rotational speeds also require a significant gearbox to drive the wheels. One way to circumvent these problems is to convert the power to electricity, which then runs the engine. While the JVT could be a "drop-in" replacement for the Capstone microturbine as a generator, the lower rotational speeds of the JVT would allow it to directly power the wheels without a complicated gearbox. With some refinements, the JVT could be used in passenger cars, opening up a market greater than $50 billion a year.

Competitors and the Introduction of the JVT into Markets.

The annual market for engines is very large – over $265 billion in 2001. The size of the market is an indication of the important role that engines play in our economy: power plants, back-up generators, pumps, boats, airplanes, and cars all contain engines of some sort. Likewise, a large number of companies produce engines of all sorts; a sample of the major manufacturers is presented in the table below.

Potential Competitors, or Licensees?

The list, shown below, is representative of the players in the field; it is not exhaustive. To compete effectively in this marketplace, General Vortex Energy would need tens of millions of dollars to build a manufacturing facility. Then, to enter each marketplace, the company would be forced to spend a great deal of money designing a task-specific engine, from a small, on-site generator for fast-food restaurants to a multi-megawatt engine for moving cargo ships across the oceans.

Natural Gas Turbine	Diesel/Gasoline Engines	Microturbines
General Electric	Caterpillar	Capstone
Rolls Royce	SEM Pielstuck	Ingersoll-Rand
Ingersoll-Rand	Isuzu	Solar Turbines
Solar Turbine	Deere	Honeywell
Dresser Rand	Detroit Diesel	UTC
Cooper Rolls, Inc.	Cummins	General Electric
Centrax Gas Turbine	Hercules	
Ansaldo Energia	EMD	
Ebara Corp.	General Electric	
European Gas Turbines	Mack	
Fiat Avio Power Division		
Kawasaki H.I. Ltd.		
Mitsubishi H.I. Ltd.		
Stewart and Stevenson		

This list is representative of the players in the field; it is not exhaustive.

This approach to launching the JVT is impractical. GVE intends to follow Rudolph Diesel's approach to the introduction of the diesel engine at the beginning of the 20th Century. Rather than build the engines himself, Diesel licensed his technology to groups that manufactured other engine designs. GVE will finish the initial development work and complete its prototype by the end of 2003. Once ready, this prototype will be used to demonstrate the effectiveness of the engine design. An outside group, such as NASA, will be used to validate the company's claims. Beyond this work, the company intends to leverage relationships with strategic partners to bring the JVT into the marketplace.

Initially, GVE will target two industries for strategic partners: (1.) the large engine manufacturers, and (2.) the power generation industries. The scale of the products in both of these industries justifies a large investment in anticipation of the improved efficiency of the JVT, the "pay-back" period being quite short. The management of GVE believes that these industries will be very likely to supply the funds necessary to build demonstration versions of the JVT that would apply to their specific needs. The licensing agreement with the strategic partners would provide GVE with an upfront cash payment and a royalty on each engine system produced. Potential strategic partners include Caterpillar, General Electric, and Siemens.

Technology validation (through a group like NASA) and the signing of a strategic partner will greatly enhance the credibility of General Vortex Energy. Once the JVT technology is validated in the marketplace, management believes that other markets will follow rapidly. GVE's current management will make use of extensive contacts in the engine and turbine industry to gain access to key decision makers involved in technology licensing at potential strategic partners. GVE has retained the law firm of Baker & McKenzie, the largest legal firm in the world, to assist GVE with the introduction to the decision makers at targeted companies. Using this approach,

the company has identified (and is currently in negotiations with) its first potential licensing partner. The GVE presentation focuses on providing scientists and engineers with enough technical information while giving upper management of potential partners a clear understanding of the value proposition: a cost-effective, fuel-efficient, low polluting power technology. GVE management believes that a licensing-based business model will be the most cost-effective means of introducing the JVT technology into the markets for the following reasons: Compelling value propositions for both the manufacturers and the end-users

• Continued focus on the company's core competency - research and development of technology

• Reduced costs to enter markets (no need to build facilities or develop new manufacturing skills)

• Minimal staff required for marketing and sales efforts.

However, management is also aware that licensing will place the company's future in the hand of manufacturers that may place a lower priority on developing a new technology (compared to driving sales of existing, profitable products). While the licensing agreements will be designed to include minimum use requirements (*i.e.*, if the licensee does not develop and market products in a timely fashion with reasonably funded marketing efforts, the license will expire), the company will take additional steps to mitigate this risk. These steps include searching out contract manufacturers and researching the possibility of developing internal manufacturing capabilities. Both of these options are less desirable, as GVE would require more capital to execute product development; however, both of these options are viable routes to producing marketable products.

iv. What is the cost/benefit of the technology (cost/ton of emissions reduction)?

Value Proposition

Although the Jirnov Vortex Turbine will be priced competitively with other technologies available in the marketplace, its real value proposition for the end user is a significant reduction in fuel consumption and maintenance costs. As shown in the table below, choosing to install a JVT over a gas turbine can potentially reduce natural gas consumption by 40,000 mcf a year, cutting the cost of electricity from about $0.07 a kilowatt-hour to $0.033 a kilowatt-hour.

	$/kW	Total Capital Costs	Fuel (mcf) for 6,000 Hr	Fuel Costs $5/mcf	$/kW-Hr
JVE	200	200,000	33,100,000	165,500	**$0.030**
	500	500,000			**$0.033**
Gas Turbine	650	650,000	73,500,000	367,500	$0.068
	900	900,000			$0.071

The value proposition calculations are based upon a new installation of a 1000 kW generator. The range of estimated capital costs for each turbine type is listed under "$/kW." The calculations assume a 16 year cost recovery period for capital expenditures. A more detailed presentation of the fuel consumption and pollutant

emission was given above. Similar cost savings can be expected in any application where fuel makes up the majority of the variable costs associated with power production. In the example shown here, the annual cost savings would completely pay for the JVT within 2 1/2 years, assuming $500,000 installation costs. Additionally, the associated reduction in pollution helps eliminate the installation of expensive "scrubbers" to keep a plant in compliance with EPA regulation. The environment-friendly technology of the JVT provides an opportunity for "avoided pollution" EPA grants of up to $3,000 / ton of pollution not released into the atmosphere.

Competitive Analysis of the Engine Marketplace

General Vortex Energy will participate in the market for internal combustion engines and gas turbines. Because there are several different ways of producing useful work, either mechanical or electrical, the competition in this industry occurs at two levels: between technologies and between manufacturers. The goal of GVE is to compete with the other technologies, but not directly with the manufacturers. Instead, the company will convert potential competition into strategic partners with licensing agreements. In the current marketplace, four primary drivers of competition are up-front (capital) costs, maintenance costs, fuel efficiency, and pollution levels in exhaust emissions.

Engine Purchase and Maintenance Costs

"Total cost of ownership" begins with the initial purchase. The simple design and smaller size of the JVT makes it easy and inexpensive to manufacture. The General Vortex team believes that a JVT manufactured in production quantities will be able to compete head-to-head with the lowest-cost competitor, the diesel engine (Figure 4). Through use of GVE's patented vortex combustion chamber, the JVT can operate at temperatures less than 1300 C., obviating the use of expensive, difficult-to-fabricate, exotic materials.

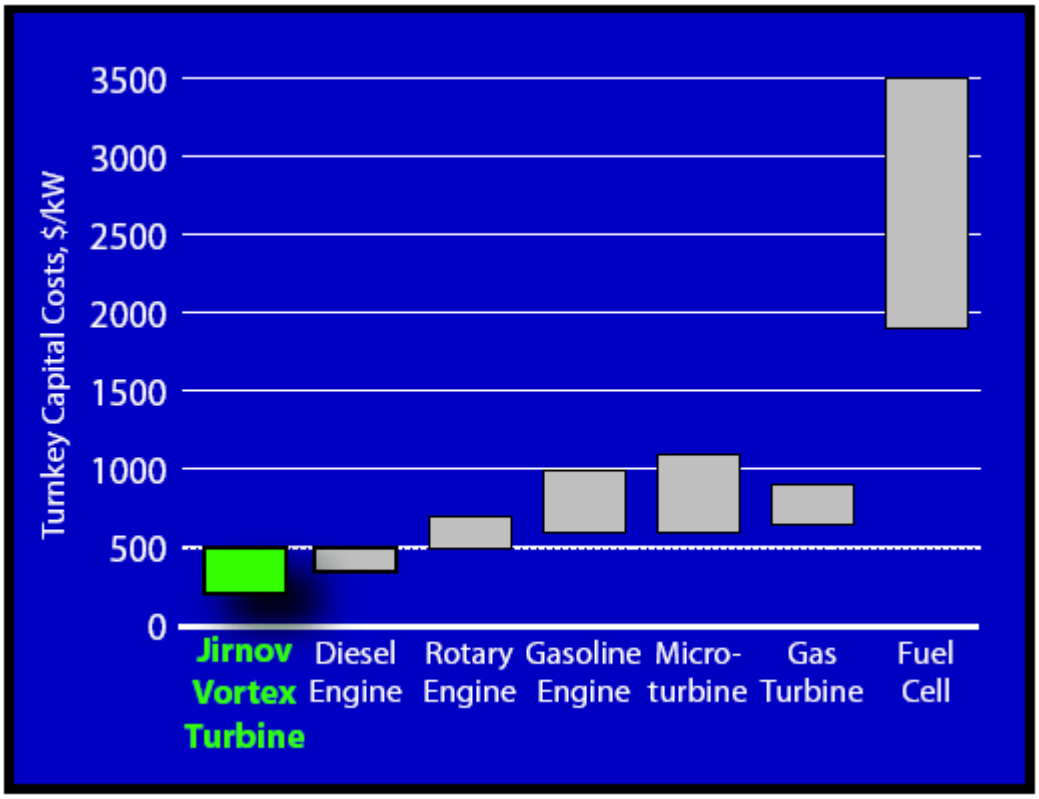


Figure 9. Turnkey Costs. Costs associated with the installation of new power generation capacity/kW.

The JVT has very few moving parts; it does not have the valves, pistons, connecting rods, and crankshafts that complicate the design and manufacture of other engines. Compared to its competitors, the JVT has only a few parts capable of failing. The JVT also has less frictional wear on its few moving components. A traditional mechanic with a minimum of additional training, rather than an expensive technician, could maintain the JVT. Because of the similarity to gas turbines, the company believes that operating and maintenance costs for the JVT will be similar or lower ($0.03 – $0.07/kW hour). The JVT should be the least expensive technology to purchase, operate, and maintain.

Fuel Efficiency.

The JVT is a unique combination of components that optimize the conversion of fuel to heat and heat to usable work – the goal of every heat engine ever made. This conversion process has been accomplished by a variety of means over the past 150 years through internal combustion engines and gas turbines. Each of these engines can be described in terms of the thermodynamic cycle that they use to convert fuel into work.

Engine Type	Uses (not a complete list)	Thermodynamic Cycle
Jirnov Vortex Engine	All markets	Modified Brayton Cycle
Turbines, Microturbines	Jet aircraft, electricity	Brayton Cycle
Diesel Internal Combustion Engine	Diesel Trucks, generators	Diesel Cycle
Gasoline Internal Combustion Engine	Automobiles, generators, pleasure boats	Otto Cycle

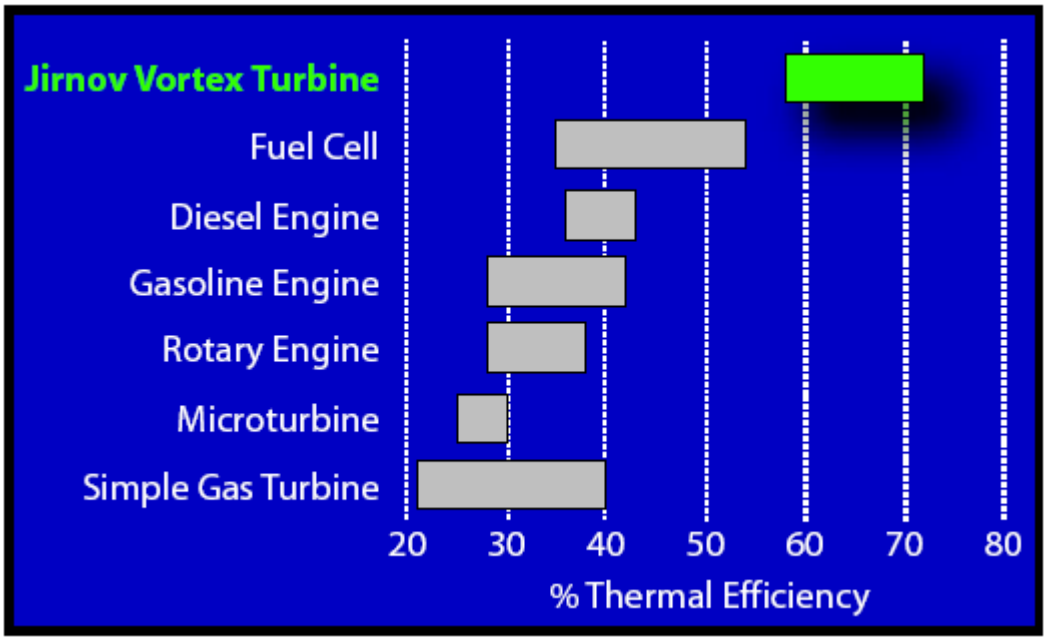


Figure 10. Thermal Efficiency. The estimated thermal efficiency of the JVT is 58 to 72%.

The JVT employs a modified Brayton cycle, similar to the thermodynamic cycle for the gas turbine, except that the compression cycle isothermal, thus requiring less work. However, several major differences make the JVT significantly more efficient than the Brayton, Otto, and Diesel cycles, or even a recent competitive technology, the fuel cell (Figure 10). Furthermore, the JVT is scalable form 10 horse power to 100 Megawatt, is able to burn a wide variety of fuels, including natural gas, hydrogen, gasoline, diesel fuel, alcohol, and even an exceptionally low-grade fuel known as "bunker fuel." The JVT is also ideal for use with bio-fuels made from renewable resources (ethanol and vegetable oils, for example). The combination of efficiency and fuel flexibility makes the JVT truly unique.

Pollution Levels in Exhaust Gases

Exhaust emissions are coming under increasing scrutiny, not simply here in the U.S., but around the globe. The various federal, state, and local regulatory authorities are interested in controlling the emissions from virtually every engine on the market. For example, the City of Houston, in an effort to reduce ozone and clean up smog, has considered banning the use of tiny two-stroke engines found in lawnmowers and leaf blowers during particular times of the day during the hot summer season. The regulation of air pollution sources will only grow stronger over time. As can be seen in Figure 4, below, the JVT produces significantly lower amounts of two of the major pollutants found in exhaust, NO_x (the major ingredient of smog and a cause of acid rain) and carbon monoxide (an invisible, odorless, and deadly gas). The JVT's low level of emitted pollution results from complete combustion of the fuel at a low temperature (less than 1300° C). With the other three technologies, either the fuel does not burn completely or combustion occurs at a much higher temperature, producing pollution.

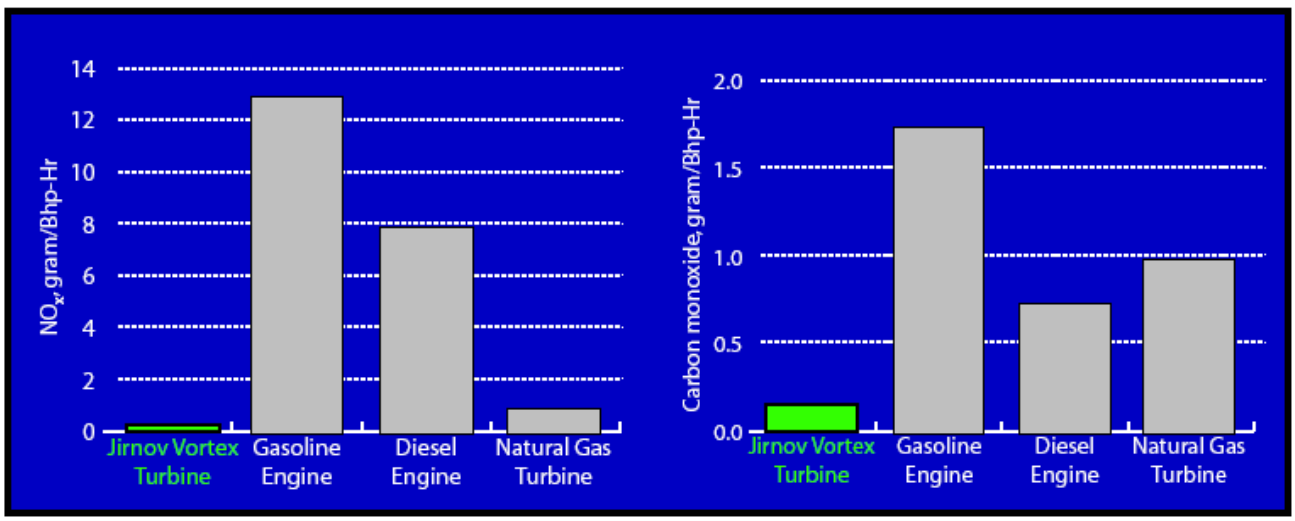


Figure 11. The amount of pollutants emitted by different engines.

A third gas, carbon dioxide, is also closely monitored by many environmental groups. Also known as the "greenhouse gas," carbon dioxide is thought to be a major contributor to global warming. When an engine burns fuel, it converts the hydrocarbons into carbon dioxide and water. More-efficient engines burn less fuel and therefore release less carbon dioxide. The JVT emits about one-half the amount of carbon dioxide as other engines or turbines. The JVT emits lower levels of these polluting gases without resorting to catalytic converters or exhaust "scrubbers" found on other engine-types. These additional components add cost and steal power from the engine. The combination of simplicity of design and reduced pollutant emissions makes the JVT an attractive alternative to existing technologies. See also the summary on Chart #1 in the Appendices.

III. Additional R&D suggestions/requirements to improve/accelerate adoption of technology. Crosscutting research needed.

Additional funding for the discovery of applications for the combustion chamber and testing for the applications would significantly facilitate the adoption of the Combustion Chamber. One such application might be in the incineration of toxic and hazardous materials, such as flaring gases at refineries. A second area would be to explore applications in the metal foundries and/or the ceramic and brick industries. Also the combustion chamber can be used in standard turbines in place of the harder to control internal combustion being currently used.

Upon the completion of the Navy STTR studies, the JVT engine will be in a position to develop production units of the engine that can be used as direct replacements to current less efficient and costlier prime motive devices such as diesels, gas engines, and current turbines.

a. Future role of the state (support? permitting? adoption?)

As we suggested above, additional funding of a marketing and testing program would expedite the implementation of the Combustion Chamber. General Vortex Energy, Inc. would appreciate such publicity and exposure as can be provided. This publicity will assist us in finding partners and joint ventures to bring the benefits of the combustion chamber and the engine to market faster.

b. Some suggested TCEQ actions recommended.

Actions would be, in addition to the publicity and exposure items listed above, to assist General Vortex in finding test and experimental sites to prove the benefits of the combustion chamber in assisting in emission reduction. With respect to the Jirnov Engine we will have a narrowed scope of needs and request in late 2004.

c. The Federal role.

The Federal role is currently being met with the Navy Grant. We also have an application under submission to the Department of Defense (Army). If we get the Army funding, it should be sufficient to take the engine development significantly closer to bringing the engine to market and to provide the environmental and economic benefits set forth above.

Planned publications, dissemination of results.

GVE is withholding the publication of results at this time in order to avoid unrealistic hype of the engine until we can give reliable assurance of the final result. A second reason is our lack of funding to pursue patent and intellectual property finalization.

Our intellectual property issues are strengthened by the granted U.S. Patent, No. 5,839,270 which describes among other claims the modified Brayton Cycle. We feel this patent is strong. At this point we are holding a wealth of Trade Secret type property, secrets that we are currently reviewing in anticipation of making patent application.

Patents: GVE holds ownership or licenses on a total of 10 patents related to energy efficiency devices.

V. Conclusions and Disclaimers

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VI. Appendices

Experimental Results of Combustion Chamber Tests.

The Vortex Combustion Chamber of the JVT burns all of the fuel in a controlled, continuous combustion process. This combustion chamber can tolerate a very lean mixture and maintain stability. During the initial liquid-fuel tests of the JVT Combustion Chamber very low levels of NO_x and CO were generated! Additionally, because of its unique design, the JVT Combustion Chamber can burn nearly any gaseous or liquid fuel, including bio-fuels.

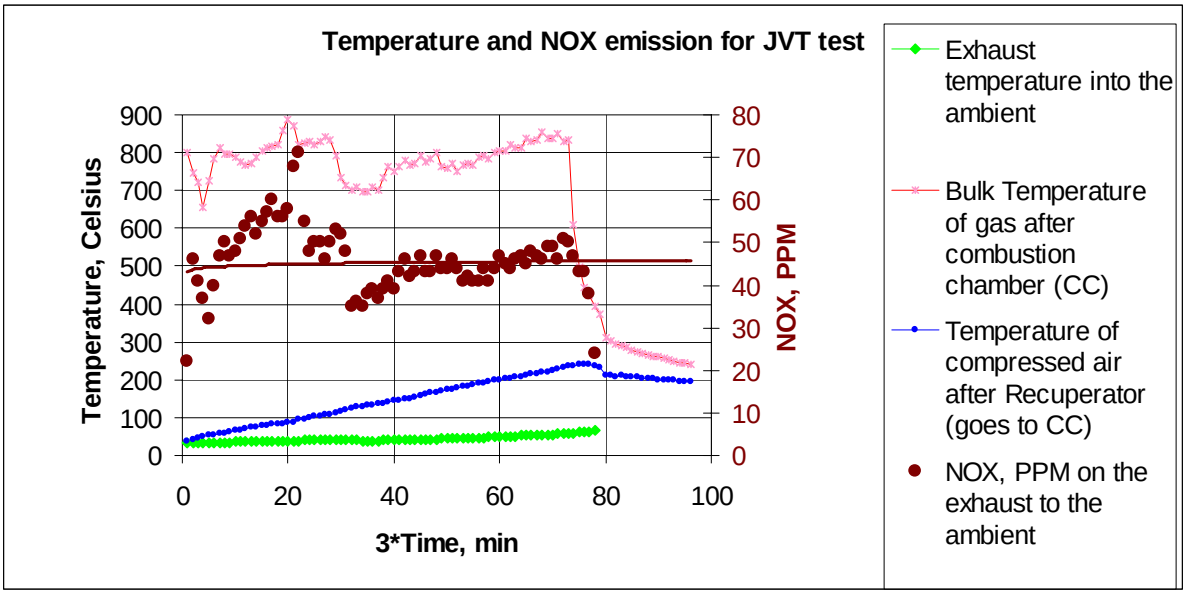

Figure 12. Test results of Combustion Chamber.

On figure 12 shown the results of testing of Combustion chamber together with Isothermal compressor and Recuperator. Fuel was kerosene. The compressed air picks up the heat from exhaust gases as it passes through the Recuperator and goes into Combustion chamber. Brown line shows the average of NO_x dots for the temperature of gas 800^0 Celsius after combustion chamber.

The Combustion chamber was tested also with the Methanol as the fuel. The results show below. The NO_x was reduced to the 25 ppm for the same temperature as for the Kerosene. The 25 ppm of NO_x was the maximum. At lower temperatures of Methanol combustion the NO_x was lower then for the same lower temperatures with the kerosene.

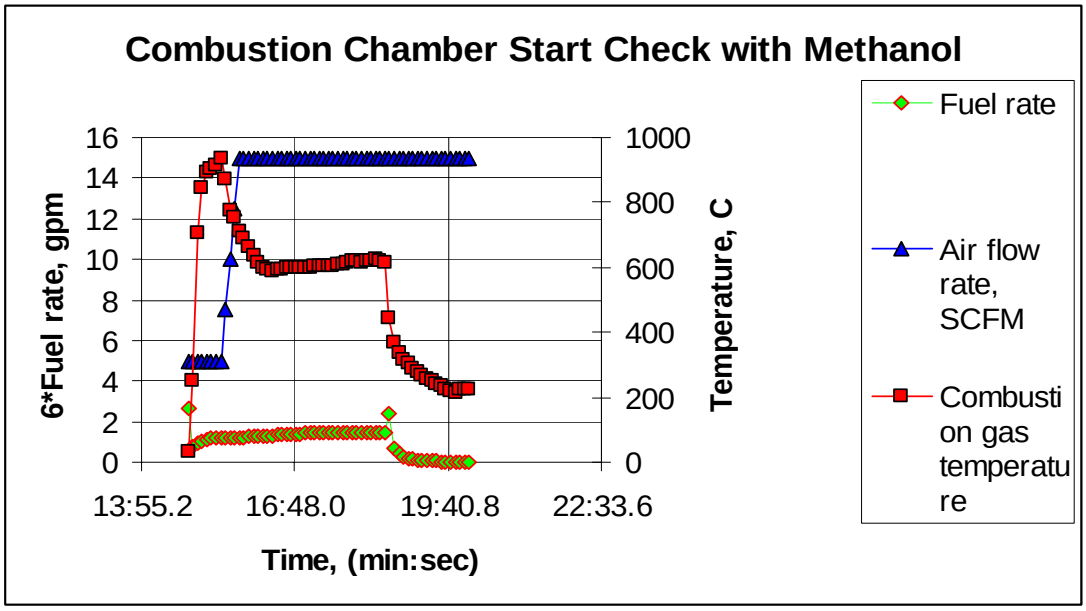

Figure 13. Experimental results for methanol as fuel.

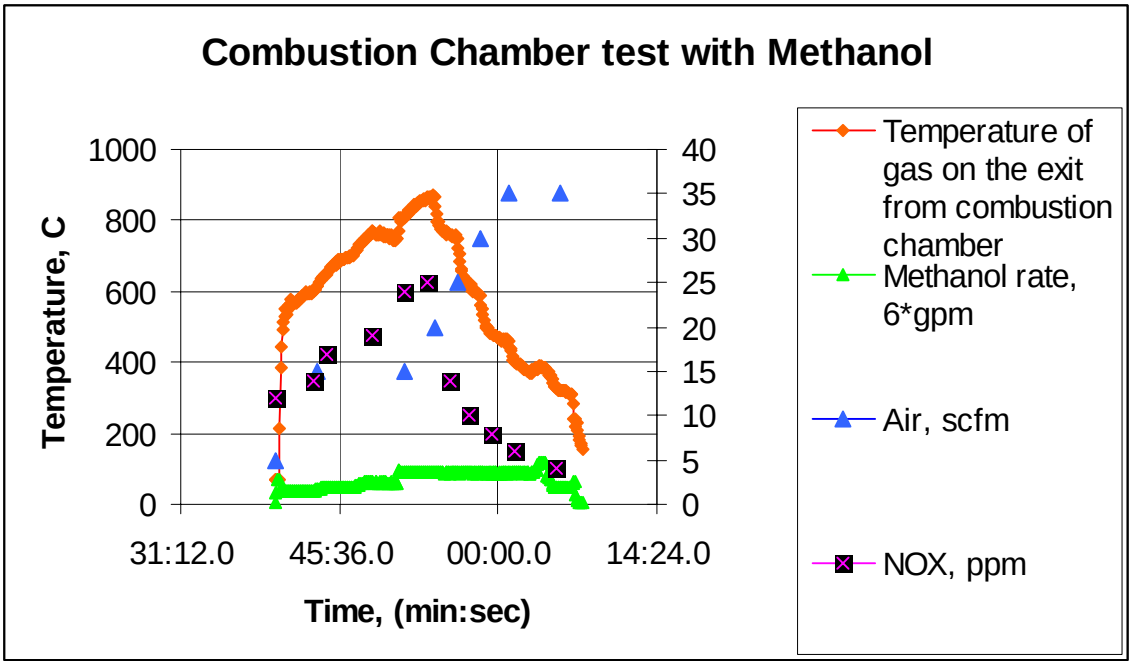

Figure 14. Continue the results for methanol.

Experimental Results of Expander Tests.

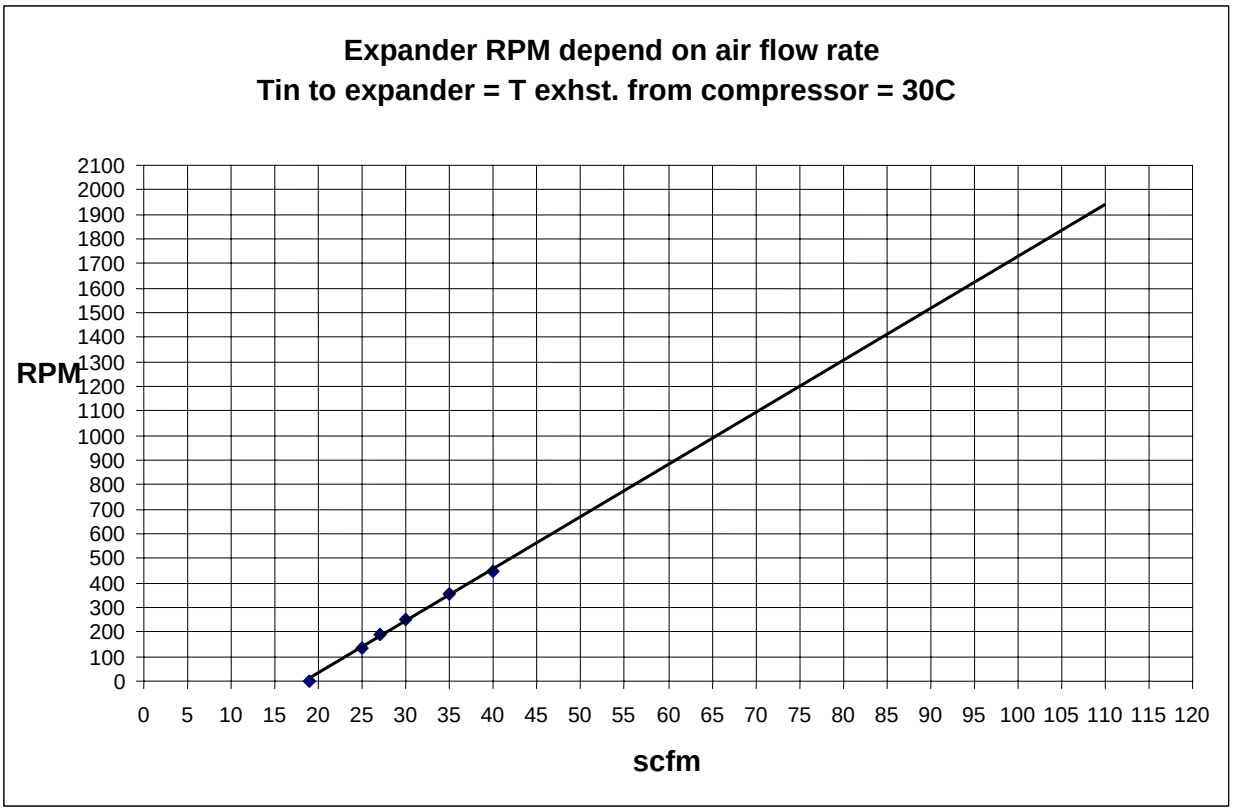

Figure 15. Expander speed vs. flow rate.

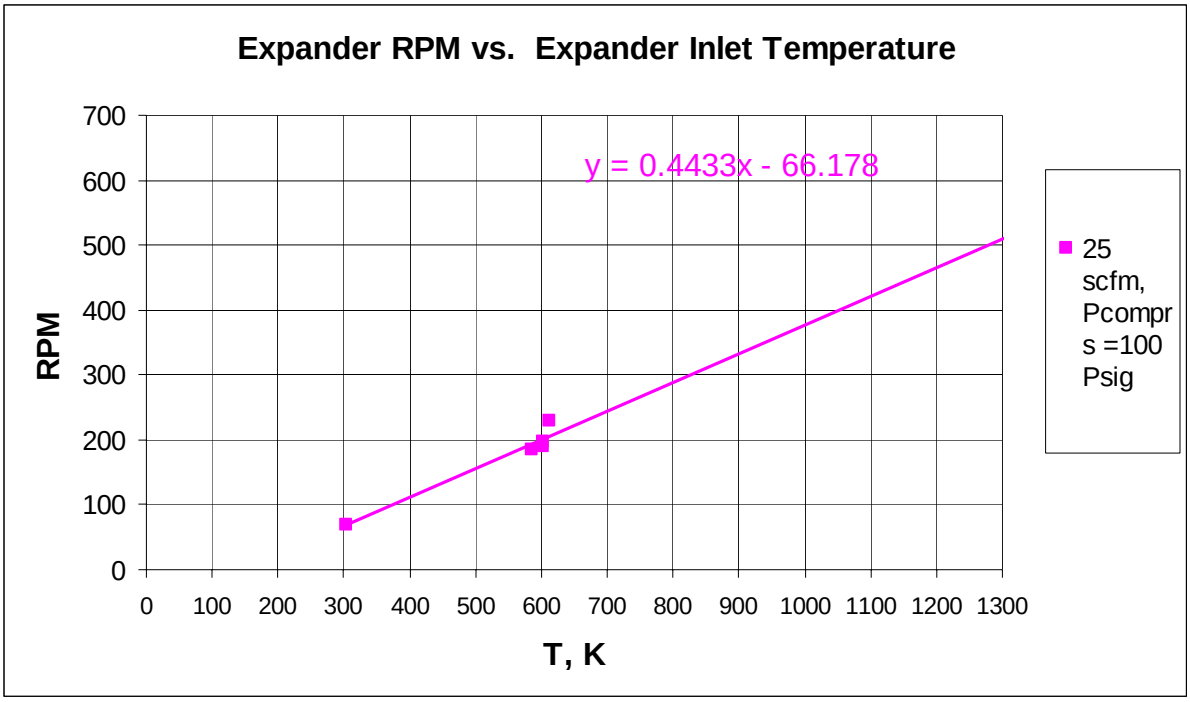

Figure 16. Expander speed vs. temperature of gas after combustion chamber.

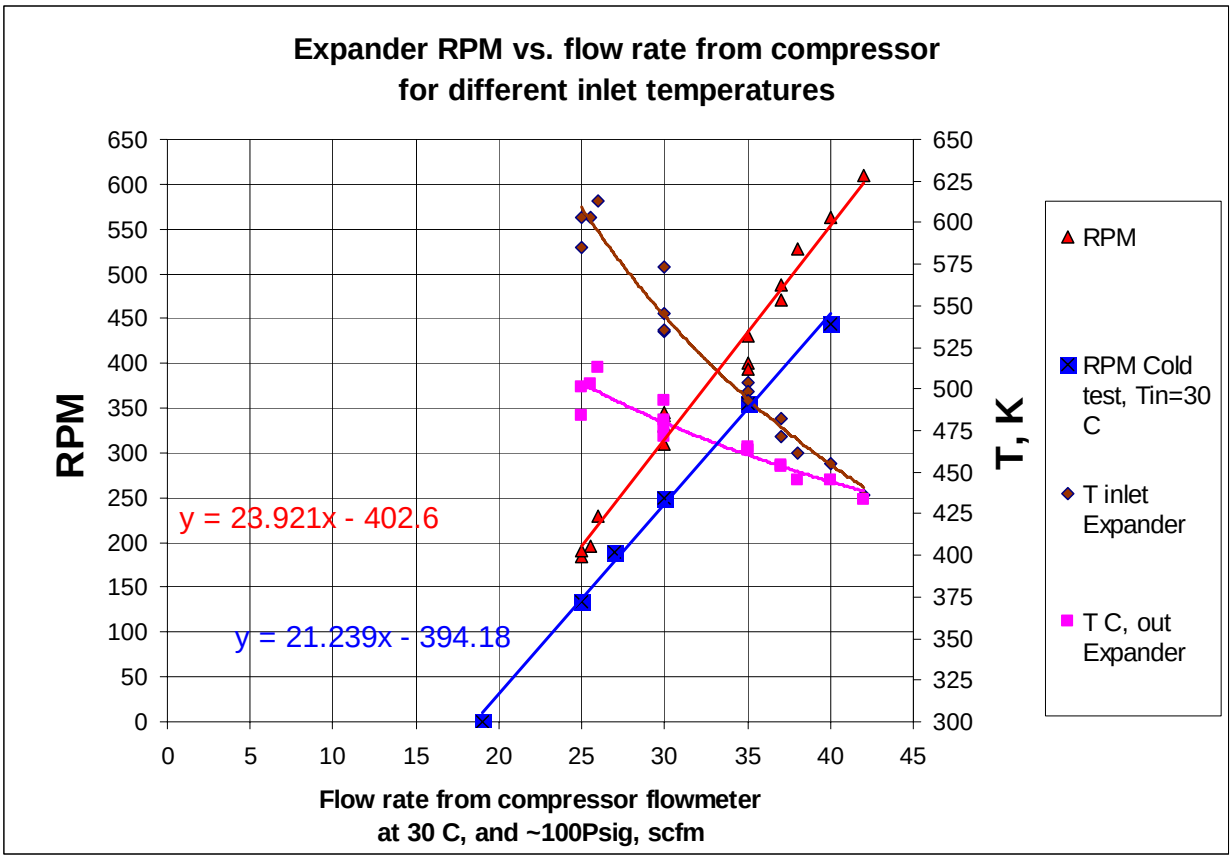

Figure 17. Expander map vs. flow rate and temperature.

Chart # 1
Economic Comparison of Distributed Generation Technologies

Technology Compa-rison	Recipro -cating Diesel Engine	Rotary Engine	Reciproca -ting Gas Engine	Simple Cycle Gas Turbine	Micro-turbine	Fuel Cell	Jirnov Vortex Engine (JVE)
Company Examples	**Cater-pillar**	**Rotary Power**	**Waukesha**	**Solar**	**Capstone**	**Ballard**	**General Vortex Energy**
Product Rollout	**Com-mercial**	**2001**	**Com-mercial**	**Com-mercial**	**1999-2000**	**1996-2010**	**2003-2005**
Size Range (kW)	20-10,000	150-1800	50-5000+	1000+	30-200	50-1000+	**1-100,000**
Fuel consumption as percentage of JVE	161-167%	207-189%	207-171%	276-180%	232-240%	166-133%	**100%**
Efficiency	36-43%	28-38%	28-42%	21-40%	25-30%	35-54%	**58-72%**
Emission as Percentages of JVE, (lean combustion) CO2	161-167%	207-189%	207-171%	276-180%	232-240%	166-133%	**100%**
NOX	322-354%	414-390%	1035-855% 2strk	552-360%	464-480%	455-470% (GT-based)	**100%**
CO	322-354%	414-390%	1035-855% (2stroke)	552-360%	464-480%	455-470% (GT-based)	**100%**
Genset Package Cost	125-300 ($/kW)	250-500 ($/kW)	250-600 ($/kW)	300-600 ($/kW)	350-750 ($/kW)	1500-3000 ($/kW)	**100-300 ($/kW)**
Turnkey Cost –no Heat Recovery	350-500 ($/kW)	500-700 ($/kW)	600-1000 ($/kW)	650-900 ($/kW)	600-1100 ($/kW)	1900-3500 ($/kW)	**200-500 ($/kW)**
Heat Recovery Added Costs	n.a. ($/kW)	75-150 ($/kW)	75-150 ($/kW)	100-200 ($/kW)	75-350 ($/kW)	Included	**included**
O&M Cost ($/kW-hr)	0.005-0.010	0.005-0.010	0.007-0.015	0.003-0.008	0.005-0.010	0.005-0.010	**0.003-0.007**

Basic system performance characteristics for engines, turbines, turbogenerators, fuel cells and Jirnov Vortex Engine. (Data based on the Rotary Power home page, and other sources).