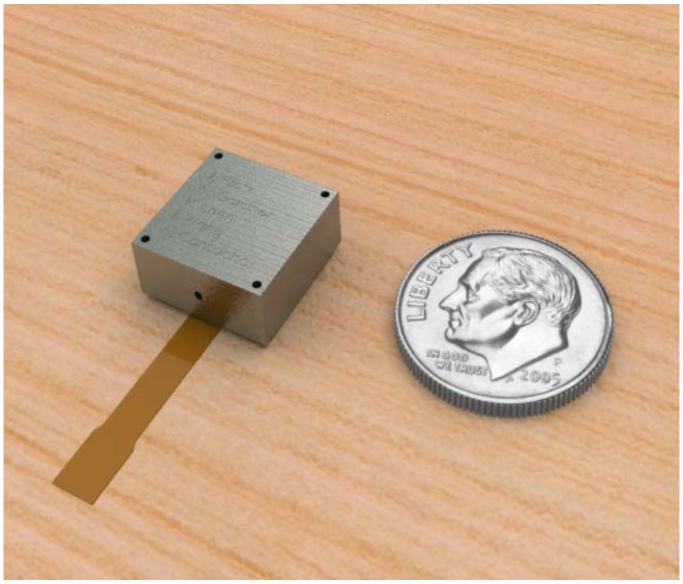
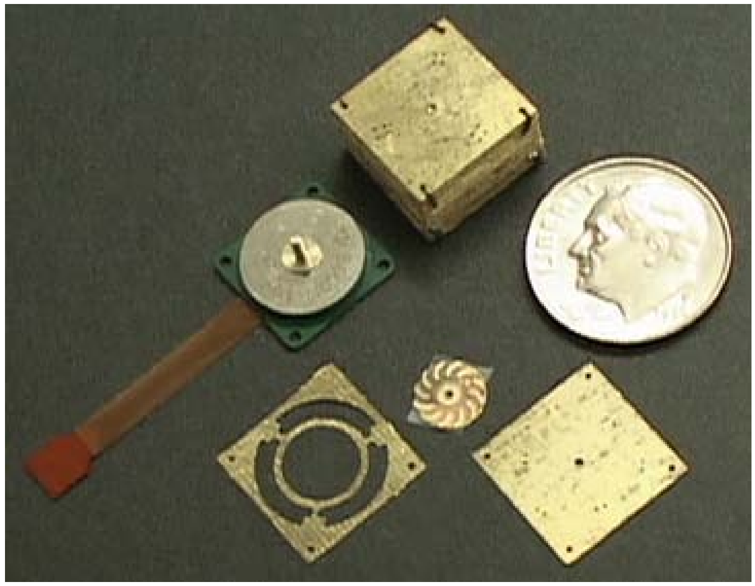
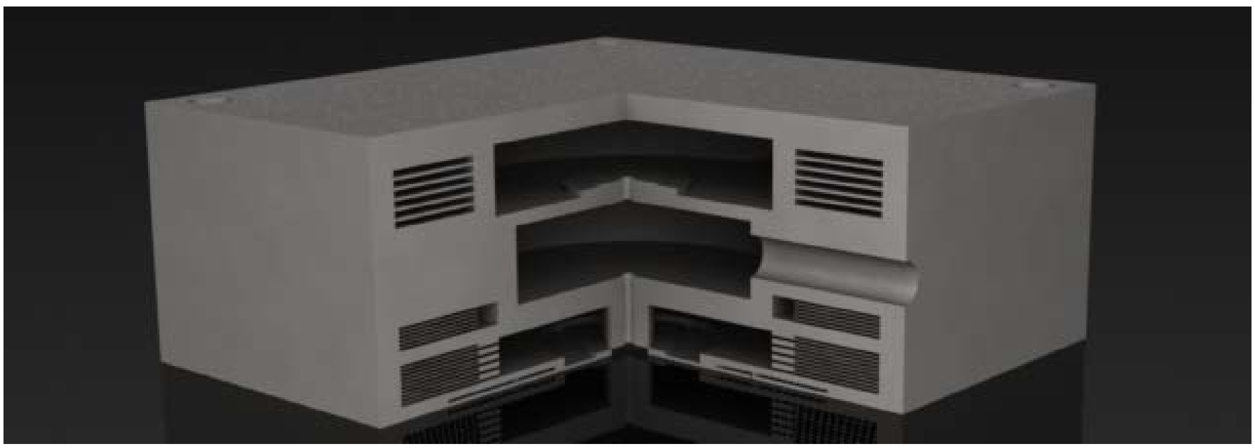
MicroPower

Advanced micro-engine system design for power generation







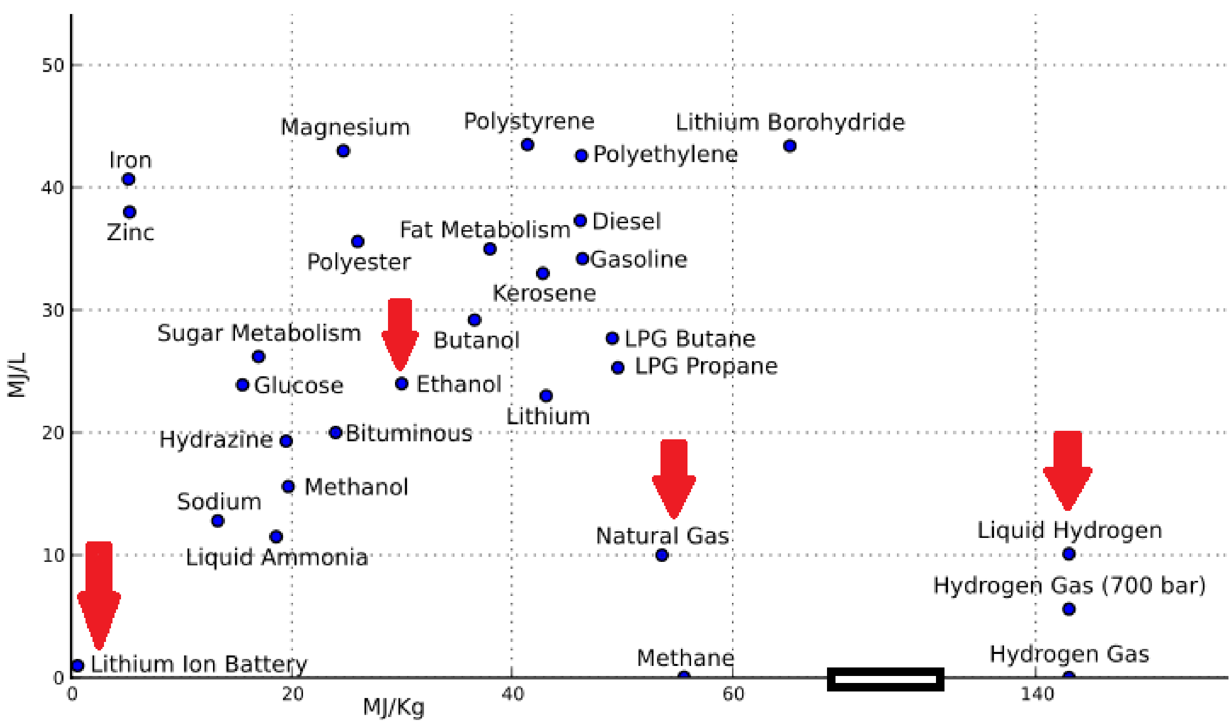
Team
Will Gardner, Pratt PhD
Hardy Shen, Pratt MEM
Ivan Wang, Pratt PhD
Andy Camacho, Pratt PhD
Shalav Gupta, Fuqua MBA

Background

Imagine running your laptop for 24 hours without having to plug into a wall socket. Imagine an autonomous military robot that can stay in the field for over a day without recharging, as opposed to the current 4 hour limit. The portable electronics market is $50 billion. Using an ethanol fueled Microengine, the revolutionary Micropower design delivers the ultimate flexibility and freedom to the consumer by delivering a 5x-10x power density over lithium batteries.

The portable electronics world has evolved tremendously over the past few decades. Everything from communications to entertainment has become increasingly mobile as the technology of these fields has advanced. In addition, even our modes of transportation are becoming increasingly dependent on portable electric power as can be seen with hybrid-electric vehicles. However, while there has been great progress in the core technologies behind these electric devices, the evolution of their power sources has been relatively stagnant. While the performance of electrical devices has increased by orders of magnitude, the performance of their power sources has increased by less than two-fold over the past two decades as Li-ion batteries have been adopted in place of NiMH batteries [http://www.allaboutbatteries.com/Battery-Energy.html].

This is solely a result of the chemistry behind battery technology, and cannot be overcome. In order to see monumental leaps in the energy density of power sources, materials with intrinsically higher energy densities such as ethanol, natural gas, and hydrogen gas must be used.
With new devices that can harness these compounds with energy densities orders of magnitude greater than currently available chemical batteries, entirely new products and industries will be developed in the 21st century.



Our Solution

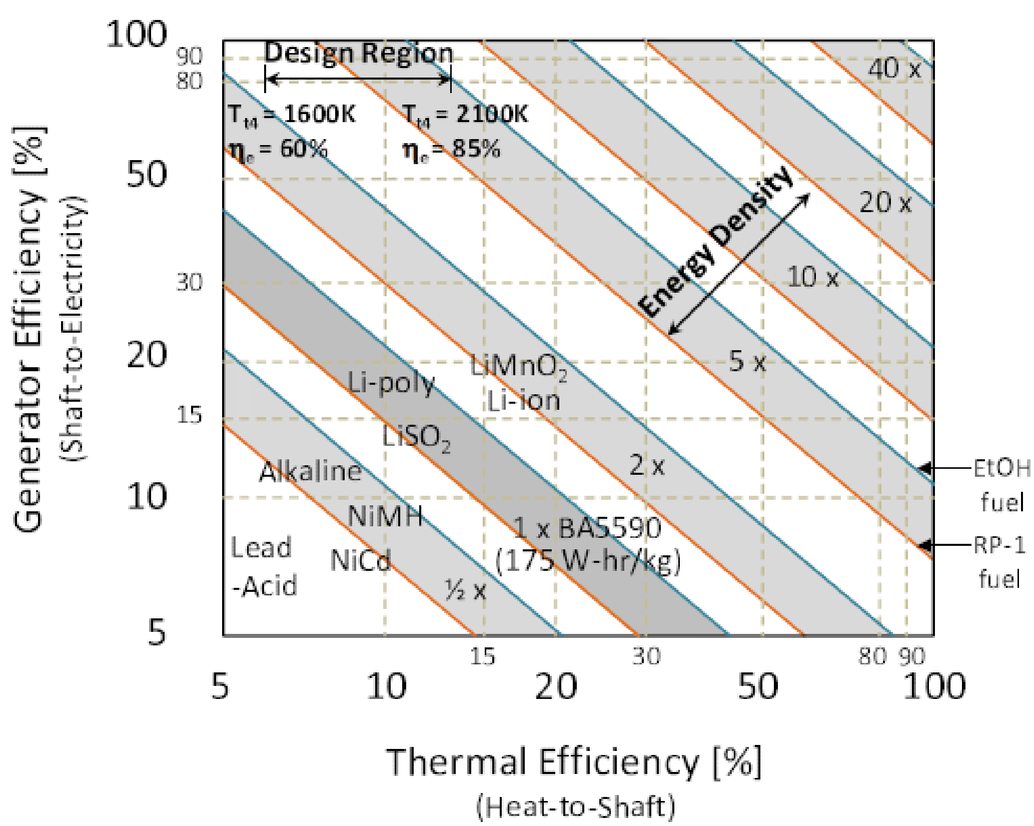
Micropower, a company started by Ph.D. students of Duke University Professor Dr. Jonathan Protz, has researched and designed the technology necessary to utilize the higher energy densities of fuels such as ethanol. The device is a micro-sized gas turbine engine.

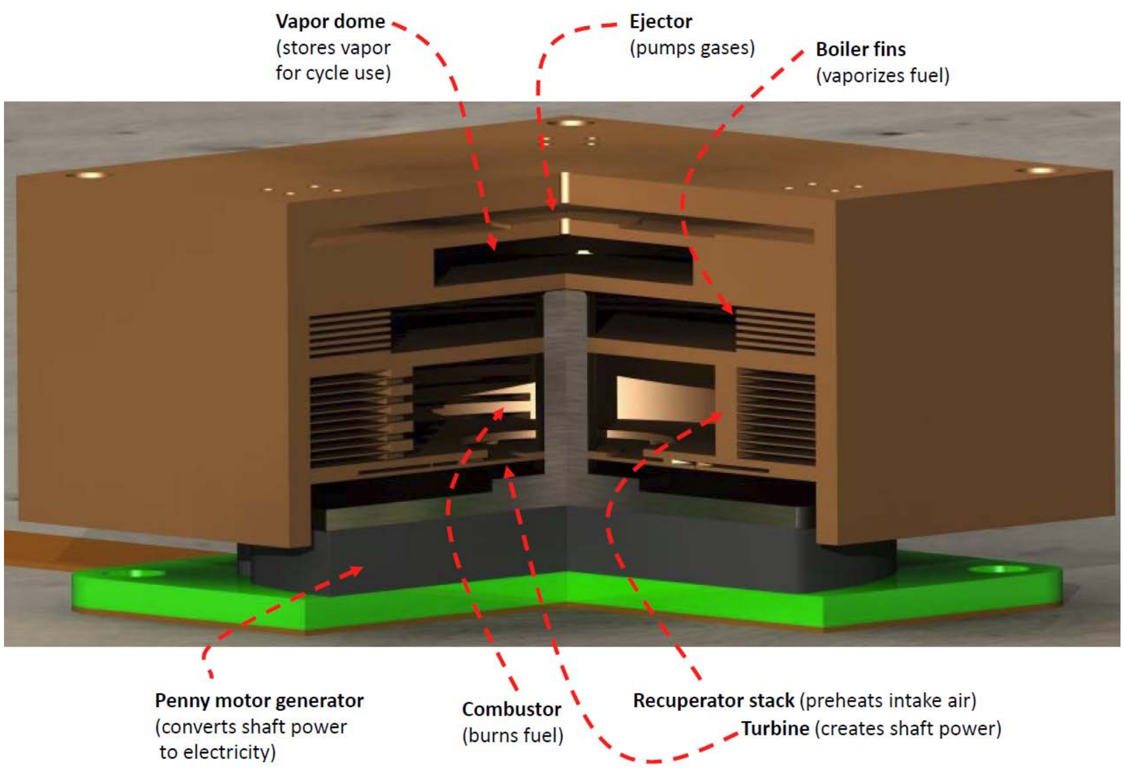
The technology and physical principles behind gas turbines are well understood and have been continually developed and improved upon for decades. Investigators have been developing mature component technologies and fabrication processes for microscale power generation components since the mid 1990's. These devices work by burning fuel to create heat. This high temperature/high energy air is then passed through a turbine rotor to create shaft power. With the use of an electrical generator, this shaft power is converted into electricity.

At conventional sizes, turbines provide the highest power densities on Earth, and it is for this reason they are almost exclusively used in power plants , whether they be coal-fired, natural gas, geo-thermal, hydro-electric, or nuclear power plants. When they are miniaturized however, their power densities increase even further, as the power density of turbines is inversely proportional to the diameter of the turbine. For this reason, the micro gas turbines designed by Micropower's engineers will provide the highest and most compact power sources on the planet, surpassing the performance of chemical batteries by orders of magnitude.

Product - Functional Summary

The Microengine functions like a high performance combined cycle power plant. Ethanol is combusted to create high pressure, high temperature gas which is then passed through a turbine to generate 10-100 Watts of electrical power in a highly compact form factor. The Microengine uses a simpler thermodynamic cycle than previous engine concepts, allowing for a reduction in rotating pumping components and reduction in risk. Engine improvements will occur through a high incremental risk, high reward component development program built upon the core cycle.





At the current time, all of main components have been designed by the Micropower's engineers; their results will be published in the scientific literature in the coming months. A fully integrated proof of concept demo engine is literally 1-2 months away, with a fully functional consumer ready prototype 1-2 years out requiring a capital injection on the order of $1-5M over the next 3 years.

Intellectual Property

Micropower's technology is derived from research conducted at MIT and Duke by Dr. Jonathan Protz (one of the leading Microengine researchers in the U.S.). Will Gardner, a student of Prof. Protz, is currently advancing the technology through his PhD research at Duke. The team filed a provisional patent for their Microengine technology in Dec 2009 for research performed on DARPA HR011-08-C-0163. The team has filed a provisional patent and is negotiating exclusive rights with Duke.

Market Opportunity: Military to Consumer Electronics and Beyond

Military

The most immediate market however is the military electronics market. Soldiers carry with them communications equipment, night vision goggles, targeting systems, GPS devices, laptop computers, etc. Currently, the most common battery of the military, the BA-5590, is non-rechargeable. This results in millions of dollars in waste yearly as the military throws out batteries that are not yet fully discharged, and whose chemicals are not recycled, but rather re-purchased [http://mobiledevdesign.com/hardware_news/radio_military_takes_aim/]. Based on Saft's investor reports, the **BA5590 annual market is ~$50M**.

Micro-gas turbines would provide not only superior performance to the chemical BA-5590 battery, but would also allow the power source to be re-used and re-filled time and time again with the same fuel (RP-8) that it is already on-site and used to power their vehicles and forward command power plants. The military is beginning to implement a **"one fuel forward"** approach to devices, and the microengine design is easily suited to perform burning RP-8 [personal communication, former DARPA program manager].

In addition to devices operated by soldiers, our microengine is a superb candidate to provide power to both current and future military robots and surveillance drones. Unmanned drones represent the future of warfare, and we can already see this trend in practice. In 2003, there were "a handful" of aerial drones and zero ground drones in service. As of April 2009, there were roughly **5,300 air drones** and **12,000 ground drones** [http://www.ted.com/talks/pw_singer_on_robots_of_war.html]. The market size for military robots is expected to go from **$831M in 2009** to **$9.7B by 2016.** These robots will need power, and the microengine will offer the military the best option.

And as with power electronics, a constant **bottleneck for robotics has been the power density of their chemical batteries.** This has limited their endurance and prevented them from acquiring more important roles, thus limiting their use and the military's demand for them. Micro gas turbines would provide the ultimate power source for military robotics applications and remove a constraint that has existed for decades.

Consumer Electronics and Beyond

The market opportunity for this technology is massive as a result of the portable electronics market being worth **$50 billion**. Not only could our micro-engine provide power to currently existing electronic devices such as portable computers, military electronics and robotics, but by removing the largest bottleneck in the electronics industry, power supplies, our micro gas turbines could completely remap the industry and allow the development of many **new types of devices that as of now cannot be conceived.**

The micro-engine also benefits from the fact that it can be powered using cleaner fuels such as natural gas and ethanol, which may make the company viable for clean tech government grants. Using a 15 watt engine sized to power a netbook, the microengine will emit **2.5x less CO_2 than an average person breathing**. In addition, our engine will emit **20% less CO_2** than a petroleum fired plant used to charge batteries on the grid. If the ethanol fuel is sourced from cellulosic biomass, it will emit **87% less CO_2**.

Lastly, the technology can be scaled to be larger, provide more power, and be used in many other applications. For example, slightly larger gas turbines would allow the power density advantages intrinsic to turbines in general to be applied to hybrid-electric vehicles, greatly improving their performance by replacing the internal combustion engines with more efficient and lighter gas turbines. It would also provide the opportunity for residential homes and commercial businesses to go off-grid and generate their own power. According to certain estimates, **if not infused with $2 trillion of**

investment over the next 2 decades, the grid will become inadequate for our power needs, making such alternatives essential [http://money.cnn.com/2009/01/06/news/economy/smart_grid/index.htm].

Microengine technology will also not be plagued with infrastructure issues. The **infrastructure to transport liquid fuels already exists** across the entire country, whether you are talking about gasoline, ethanol, or natural gas inside the home. The military also has the necessary infrastructure to transport liquids such as water and fuel to wherever it is needed.

Go-To-Market

As mentioned before Micropower's product has two natural markets: Military & Commercial. The company plans to enter the military market first.

Contingent on development of a successful prototype, Logos Technologies has agreed to partner with Micropower in exchange for equity (terms have not been negotiated). Logos has a long track record of securing DARPA grants and military contracts as they have necessary security clearances and vendor qualifications. Government grants (i.e. DARPA) to fund Micropower's R&D efforts will enable development of demo units for trial in military environments without the need for a larger round of equity financing.

Success in the military market will establish product credibility and a preferred vendor status for Micropower. It will establish manufacturing and supply infrastructure, and domain experience. The military contracts will provide Micropower with organic cash flows preparing it to build low cost, highly scalable commercial products. For demonstration purposes, a **10% penetration into the 4M unit ultraportable laptop market at a unit price of $500 gives revenues of $195M per year.** This unit price is consistent with OEM replacement batteries for laptops such as a Macbook Pro.

Industry Analysis –

The current battery industry consists of a few large OEM manufacturers such as Panasonic, Sony, and Sanyo. The current battery industry is characterized by low profit margins, large scale capital intensive manufacturing, and high costs to entry.

Micropower does not intend to directly compete with these companies by producing superior batteries, but rather hopes to develop a product in an entirely different class. One that requires a skill set to design and manufacture which these companies do not posses.

Due to the diverse and extremely inter-disciplinary nature of the complex and varied technologies in the microengine, the knowledge base and skill set required to produce such an engine is outside of expertise of potential competitors in the industry. The creation of a micro gas turbine engine calls for a combination of micro sized turbo-machinery, recuperators, combustors, injectors, ejectors, boilers, electrical generators, and power electronics. In addition, an understanding of the discipline of chemical etching, micro-layer assembly, and the design constraints that accompany these processes is required. Only a few large companies currently have the resources and expertise necessary to pull together and integrate all of the various technologies. However, the start-up time required to integrate all the technologies and train the appropriate engineers, in addition to overcoming IP issues, would make it more likely that these companies would attempt to acquire Micropower rather than trying to directly compete. Micropower considers this to be a potential exit strategy.

Team

The team behind Micropower consists of highly self-motivated and achieved individuals who all share a passion for the technology behind the micro engine and its success. With the exception of one member, Shalav Gupta, who is in responsible for the business aspects of the company, the team consists exclusively of highly technical and skilled Duke engineering MS and Ph.D. students who have been working with the technology behind the micro engine throughout their graduate careers. So far in their research they have created the **world's highest power density pumping device** (250 kW/L) with no moving parts, compared to MIT's microturbocharger (80 kW/L). Their research focus is on investigating the lower size limits of microengine components, which ultimately sets the peak power density. They were also able to fabricate the demo prototype on the opening page using **a printer, an iron and about $20 worth of chemicals and brass.**

Will Gardner – Will is a Duke Ph.D. mechanical engineering student working underneath his advisor Dr. Protz. He is the lead system designer and handles the ejector, injector, recuperator, and combustion chamber components. Will lead the Duke University Formula SAE team to consecutive best finishes at Michigan International Speedway in 2007,2008 and 2009.

Hardy Shen – Hardy is an Duke MEM student. Hardy is responsible for system fabrication, packaging, and design. He is the head CAD designer of the team. Hardy was also the drivetrain and fabrication design leader for the Duke University FSAE team.

Ivan Wang – Ivan is a Duke Ph.D. mechanical engineering student. Ivan is the lead programmer on the team and is deals extensively with dynamics of the turbo-machinery and pumping components. Ivan is also skilled with CNC machining, with experience coming from being the wheels, hubs and braking assembly design leader on the Duke University FSAE team.

Andy Camacho – Andy is also a Duke Ph.D. mechanical engineering student. He is the lead designer of the turbo-machinery components and also the designer of the power electronics components of the engine.

Shalav Gupta - Shalav is a second year MBA student at Fuqua, Duke University. He has over five years of experience in technology consulting and management roles with firms such as Capgemini, British Telecom and Johnson & Johnson. Shalav was a finalist in the Duke Start-Up Challenge last year. Shalav is leading marketing and business development.

Advisors

Dr. Jonathan Protz – Professor Protz received went straight through MIT and received his PhD in 2000 for his work leading MIT's microengine project. He is now an assistant professor at Duke's Mechanical Engineering department and was the original inventor and designer of many of the key components in the microengine.

Jason Massey - Jason has worked as a venture capitalist for 7 years in Silicon Valley and is now an active advisor and angel in several startups including Quantios, Tapulous and Mission Motors. He is often a guest lecturer on entrepreneurship at his alma mater of NCSU as well as Elon and Duke.

Business Model

In order to turn a profit the company will focus on its core competencies which is the research, design, and development of micro engines. Many of the more capital intensive activities such as manufacturing will be originally outsourced to companies which currently posses the capabilities to manufacture all the required components. In addition, many components such as micro-electric generators will simply be purchased as opposed to designed and manufactured from scratch.

Micropower's first customer will be the U.S. military. Focusing on the military market at first is a natural choice. For military robotics and electronics applications, the most important features will be performance and reliability. Focusing on this market at first will give Micropower the revenue and time necessary to invest in R&D until the technology is ready for consumer and industrial market applications. Following this approach will allow the Company to fine tune various iterations of engine designs until a commercial version is deemed viable.

Tackling the military market first will be achievable due to a partnership between Micropower and Logos Technologies, an experienced military contractor who has been working with Micropower throughout the engines development and who holds an equity stake in the company. Logos has a long track record of securing DARPA grants and military contracts as they have necessary security clearances and vendor qualifications.

Once the military level of development is reached and the market is saturated, microengine technologies will be advanced and developed enough to serve the entire portable consumer electronics industry. Also at this point, the per-unit costs of such engines should be substantially less, bringing the cost of an engine to within the reach of average consumers. This is due to the highly scalable process by which all the individual components are built, allowing huge volume production runs. Such an outcome would be the best case scenario, with the market size of the portable electronics industry valued at $50 billion. A base financial outcome would consist of Micropower serving solely the military battery market. This market is almost exclusively supplied by BA-5590 batteries from Saft Batteries, with 350,000 units being purchased yearly at a cost of $100 each for a total of $35 million. [source]
http://www.prc68.com/I/BA5590.shtml

However, due to the increasing importance of electronics and robotics for military applications, this market size will increase significantly in the upcoming years.
Primary military revenues will come from three sources: OEM sales of micro engines, sales of replacement parts, and the repair and servicing of existing engines.

Use of Proceeds and Finances

Micropower will use the $25,000 proceeds from the Duke Start-Up Challenge to complete the prototype in order to secure the partnership with Logos Technologies, which would lead to additional funding via government grants. Here's a high level break up of our use of proceeds:

- $20k for 2 fabrication runs producing **50 functional demo prototypes.** The engines will be fabricated using a highly scalable chemical etching process performed by a large firm in Chicago.

- $5k for peripheral equipment including generators, circuitry, etc

A working production quality engine would be expected at the end of 2010.

Micropower estimates that we would require approximately $2 million to reach this milestone. In the year 2011, the Company estimates that it would need an additional $3 million dollars for appropriate testing and trials. In the year 2012, the company expects to be income neutral and to begin seeing a profit in the year 2013.

In addition to seeking debt financing and VC funding, the Company plans on actively pursuing Federal Small Business grants, various renewable and green energy grants provided by the Department of Energy, and with the assistance of Logos, acquiring military research and development grants for high tech products through organizations such as DARPA.

Competing Technologies

There are two competing technologies to micro engines. The first of these technologies are advanced batteries. However, the technology behind batteries is very mature and has proven in the past to only show incremental performance improvements. The purpose of the micro-engine is to provide performance that is an order of magnitude greater.

In addition, fuel cells are another competing technology. This technology however has been in development for decades. For example, fuel cells were used on the Apollo Lunar Lander. However, the same perennial problems have continually prevented the technology from seeing widespread adoption in the market place, despite using the equivalent higher energy density fuels of the micro-engine.

Gas turbines on the other hand have seen almost exclusive adoption in power plants across the world, demonstrating the reliability and performance of the physical principles behind the technology. The goal of Micropower is to take this technology, miniaturize it, and provide the same benefits to the all portable electronic devices.

Investment Demand

Private investors and now the public market have shown a strong appetite for investments in the advanced battery and energy storage/energy creation space as evidenced by the public launch of Bloom Energy and the following ventured back startups:

Lilliputian Systems - $78 million in financing from premiere venture capital firm Kliener Perkins. Lilliputian has built a similar product as Micropower, albeit different technology and process. They use larger fuel cell technology which requires expensive materials.

A123 - Just completed a $378 million IPO with a 50% jump in stock price on first day of trading.The company had raised over $132 million in private venture capital funding. They use lithium-ion battery technology in the automotive space.

SEEO - $8.6 million Series A from Khosla Ventures for advanced lithium-ion batteries.

Bloom - $400 million raised using fuel cell technology. Current units cost ~$1M dollar, and produce 100 kW and weigh 10 tons. This power density is roughly that of an automobile from the 1920's.

These are just four examples of several startup companies that have experienced successful fund raising. Micropower expects to benefit from this trend and given its unique technology and potential has **already had preliminary interest from top tier Silicon Valley venture capitalists** through our advisory board. An investor pipeline list is available upon further due diligence.

Conclusion

Computers use to take up entire office floors but were then shrunk and achieved wide scale adoption due to miniaturization of its transistor components. We believe micro-engines will follow a similar path and bring incredibly higher power densities to the world. This will spawn new devices, new industries, and change the way in which energy is stored and utilized across the globe.