Revolutionary Hybrid Battery

Clarian's innovative rotary generator transforms the way power is generated and enables a revolutionary new hybrid battery. Originally developed as a power source for the Department of Defense Humanoid Robot Program, the rotary generator is compact, lightweight and has only two moving parts, making it reliable, safe, and easy-to-maintain.

Clarian developed the patent-pending rotary generator to enable an energy efficient, carbon neutral power source that can be used in a broad range of applications including electric vehicles, robots, unmanned vehicles, stationary or portable generators for homes and remote locations, or as a range extender for electric vehicles. Think of the rotary generator as a powerful self-contained electromechanical battery...

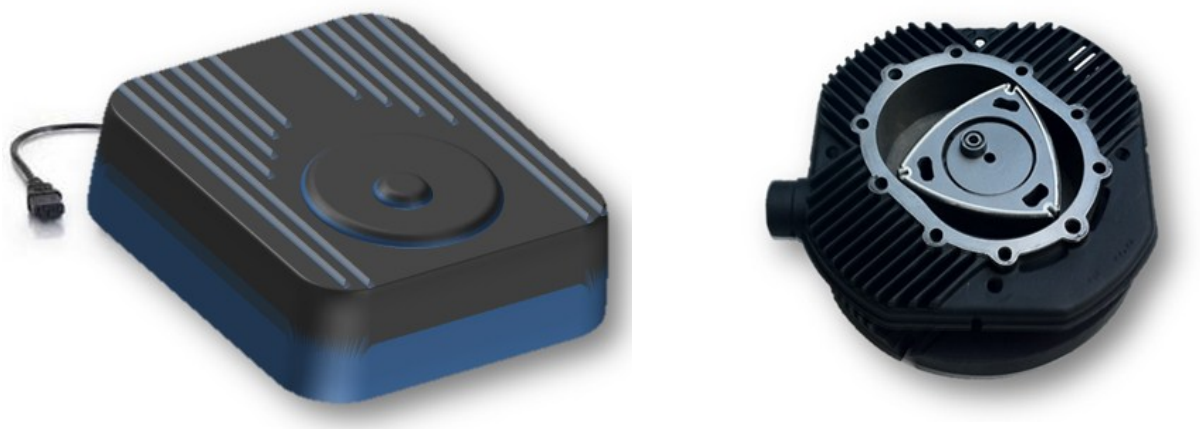


FIG. 1: Artist's Concept of a Hybrid Battery and Cutaway View of an Early Generator Prototype

Background

The energy density of hydrocarbon-based biofuels is over 20-30 times greater than existing battery technologies. Even at 30% conversion efficiency, hydrocarbon-based biofuels provide as much as 10 times more energy density than a typical battery - roughly 2.3kWh/kg vs. 0.2kWh/kg for a typical battery. As a result, devices powered by a rotary generator can be lighter, operate longer and provide greater on-demand boost power than those powered by traditional batteries. In addition, these devices can be "recharged" within seconds by swapping out a compact refillable (and recyclable) fuel cartridge and they have cycle lives many times greater than traditional batteries.

Clarian's rotary generator is based on a well-established rotary engine design modified to generate electric power without the need of a separate generator assembly. Rotary engines are well suited for the task because of their compact size, high power-to-weight ratio, greater volumetric efficiency, fewer moving parts, reliable operation and ability to run on a variety of low emission and carbon neutral biofuels including hydrogen. As well, the flat rotor surfaces found in a rotary engine are ideally suited for low-friction ceramic seals (vs. steel piston rings in a traditional piston-driven engine). Moreover, improved spark plug and exhaust port configuration have resolved fuel efficiency and emissions issues that plagued earlier rotary engine designs.

What makes the rotary generator unique is that it doesn't have an output drive shaft like a traditional piston-driven engine – the generator's only output is the electricity generated by the unique induction generator design incorporated into the patent-pending rotor assembly (US Publication 20110133486). The result is a compact, lightweight source of electricity that is fully self-contained – no bulky generators, flywheels, alternators, fan belts, pulleys or gears to worry about. Think of the rotary generator as a powerful self-contained electromechanical battery.

Technical Advantages

- Compact and lightweight size without the need of separate generator, starter or gearbox, and able to operate and survive in challenging environments
- Capable of running on a variety of low emission and carbon neutral biofuels, including propane, natural gas, ethanol, methanol and even hydrogen
- With only two moving parts and the elimination of complex valve trains, the rotary generator provides greater reliability and more efficient power flow, is able to run reliably at higher RPM, and is virtually immune to catastrophic failure – even with loss of compression, cooling or oil pressure, the rotary generator is able to continue producing power
- Greater volumetric efficiency and more than double the power-to-weight ratio of a traditional piston-driven generator; the all-aluminum block and piston with low-friction ceramic seals reduces friction loses, improves efficiency, reduces rotor wear, and further increases the power-to-weight ratio
- Simplicity of design and smaller size allows for savings in manufacture and assembly costs
- Unique asynchronous rotor operation enables on-demand boost power, while enabling lower fuel consumption during normal operation
- Brushless induction-based generator armature reduces maintenance and provides durable operation
- Scalable design of the rotary generator enables ground-breaking hybrid batteries of virtually <u>any</u> size

Generator Design and Operation

The design of the rotary generator is well adapted for use in vehicles, robots, unmanned vehicles, stationary or portable power generation for homes and remote locations, or as a range extender for electric vehicles.

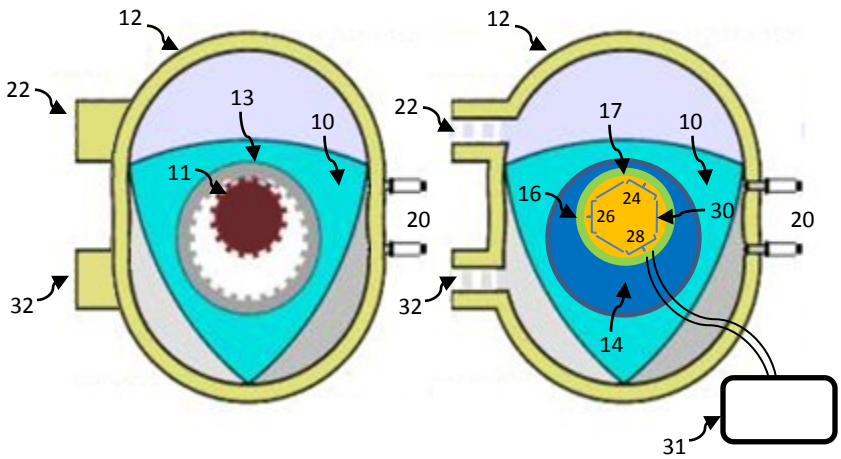


FIG. 2: Cross-Section Schematics of Rotary generator

FIG. 2 above is cross-section schematic of the rotary generator. As with a typical rotary engine, a rotary piston (10) revolves around an eccentric armature (14) and a fixed gear (11) attached to a rotor-housing wall (the rotor-housing wall is not shown in this view). Unlike a typical rotary engine however, the eccentric armature rotates around a fixed shaft (17) as shown in FIG. 2 and is configured to rotate freely inside the rotor chamber – there is no external drive shaft, power generation is fully self-contained within the rotor housing.

The rotor assembly described above includes a copper or aluminum reaction plate (16), which is positioned to rotate around a set of power converter coils (24, 26 and 28) mounted to the fixed shaft, which together form a power converter (30). The eccentric armature, and in turn the rotary piston rotate by application of electrical current to the power converter, which induces an electromotive force on the reaction plate located inside the rotor assembly and starts the generator. Similarly, the power converter can be configured to convert mechanical energy of the rotary piston to electrical energy, which is then transferred to an external energy management system (31).

An intake port (22) allows a fuel mixture supplied by a carburetor or fuel injection system to enter the rotor chamber when the apex of the rotary piston passes over the intake port, and drawing the fuel mixture into the rotor chamber. Motion of rotary piston past the intake port is driven by application of electrical current to the power converter. The fuel mixture is compressed by further rotation of the rotary piston-driven by continuing to apply electrical current to the power converter. As with a typical rotary engine, the compressed fuel is ignited by spark plugs

(20) and during the subsequent power stroke, the reaction plate rotates around the power converter, inducing an electrical current in the power converter coils, which is then transferred to the energy management system. Once the power stroke is completed, the rotary piston continues to rotate forcing exhaust gases out of the rotor housing through an exhaust port (32), and the cycle repeats itself.

Note: for simplicity, a simple intake and exhaust port are shown in FIG. 2; however the exhaust ports on the rotary generator are located on the end faces of the rotor housing for increased fuel efficiency. Additionally, the rotary generator uses a unique patent-pending thermal cooling system that maintains the temperature of the generator, in particular the power converter, well within a normal operating range.

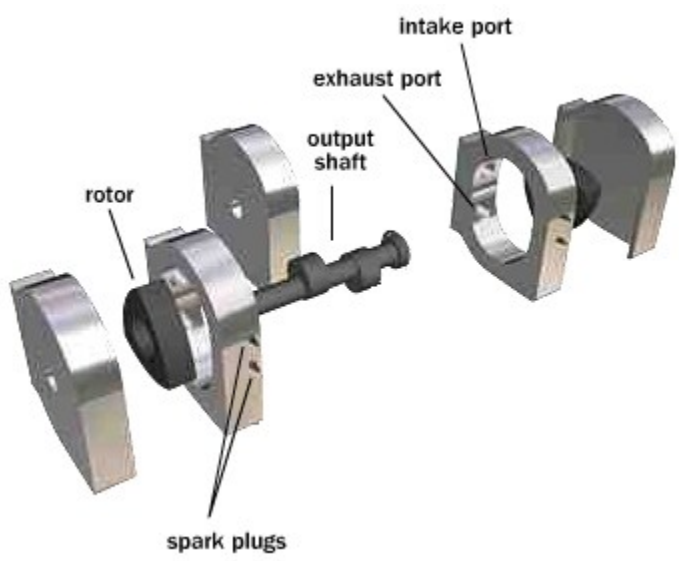


FIG. 3: Typical Rotary Engine Assembly

Operation and Increased Efficiency

The operation of the generator's power converter is controlled by a digital energy management system (EMS). The EMS determines the timing and the magnitude of energy transferred into and out of the power converter based on: the location, velocity and acceleration of the rotary piston, and the pressure, temperature, density and mass of the fuel mixture.

FIG. 4 illustrates a typical four-stroke rotary piston cycle. To start the generator, the energy management system supplies electrical current to the power converter, rotating the rotary assembly and drawing the fuel mixture into the rotor chamber as an intake stroke. The power converter continues rotating the rotary assembly as a compression stroke, compressing the

reactants in the rotor chamber. A reaction between the reactants is then initiated by a spark plug, rotating the rotary assembly as a power stroke. During this power stroke, the rotary assembly continues to rotate, exhausting any reaction products and converting mechanical energy of rotary assembly to electrical energy, which is then transferred to an energy management system. The cycle is then repeated for each four-stroke cycle.

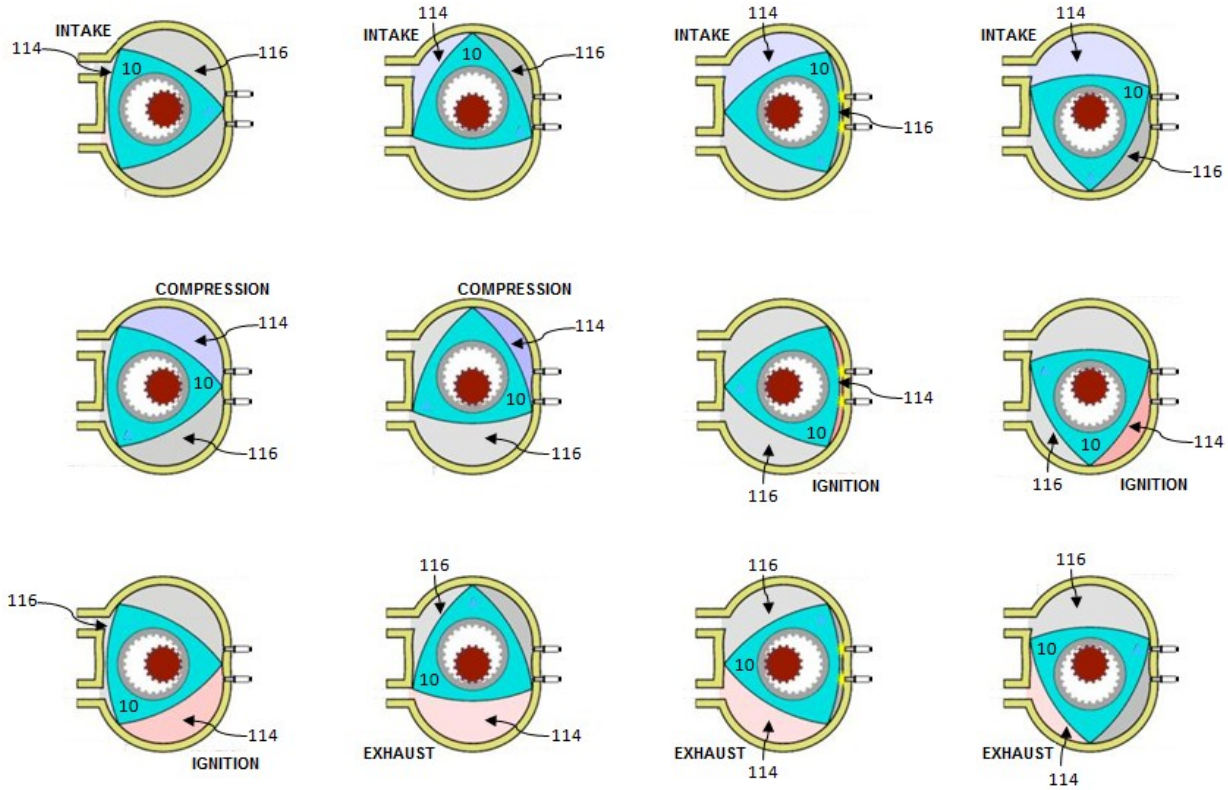


FIG. 4: Four-Stroke Rotary Engine Cycle

However, what makes the rotary generator unique is that the motion of the patent-pending rotor assembly is not constant. The actual motion of the rotor assembly is controlled by the EMS and involves more complex velocity profiles, continuously changing velocities and finite accelerations to optimize fuel efficiency, control vibration and limit peak loads on the generator structure. Drawing power from the generator electromechanically allows the generator to vary the duration of the power stroke for greater thermodynamic efficiency and optimize generator performance under varying conditions of speed, load, temperature, air density, fuel ratio, etc.

Asynchronous Rotor Operation

In a typical configuration, the rotary generator has two or more rotor assemblies, a primary rotor assembly and one or more secondary rotor assemblies. Unlike a typical rotary engine however, the primary and secondary rotor assemblies are not coupled to one another via a crankshaft and can be operated synchronously or asynchronously as needed. For example, the primary and any secondary rotor assemblies may operate at different cycle frequencies to provide boost power or improved fuel efficiency, or the primary rotor assembly may operate alone while any secondary rotor assemblies are turned off to reduce fuel consumption when loads are lower.

Energy Management System and Boost Power

The Energy Management System is comprised of a processor-based controller for managing the operation of the primary and secondary rotor assemblies, the power converter, additional generator functions such as combustion timing, fuel mixture, cooling, etc., and a built-in capacitor bank that can be used to start the rotary generator and provide short power boosts if needed.

Global Market Opportunity

With a wide variety of applications, from electric vehicles to portable and backup generation for homes, to remote locations for use in humanitarian aid missions or forward operations, the rotary generator has significant global market potential.

About Clarian Labs

Clarian Labs is an award-winning technology incubator focused on developing the latest in energy-saving technologies. We believe that our commitment to this mission will in turn ensure the long-term sustainability and security of our communities.

Consumer Innovation Award
Ecomagination Challenge
Powering the Grid

Clarian is the winner of GE's Consumer Innovation Award in the 2010 Ecomagination Challenge, a global search to find and fund the most innovative clean technologies. Clarian's SmartBox Solar™ module was selected from more than 3,000 entries for its feasibility and potential impact by GE and venture capital leaders.

Research and Licensing Inquiries

Institutional research and licensing inquiries should be directed to partners@clarianlabs.com.

Frequently Asked Questions

How is rotary generator different from other electric generators?

Unlike a piston-driven engine that delivers power through a drive shaft, the only output from a rotary generator is electricity. Everything is self-contained and doesn't require a separate generator because electricity is actually generated inside the patent-pending rotor assembly (US Publication 20110133486). The result is a compact, lightweight power source – there are no external storage batteries, no bulky generators, flywheels, alternators, fan belts, pulleys or gears to worry about. Even the starter is built-in.

But a combustion driven generator is nothing new…

No they aren't, but the rotary generator is. Unlike a piston-driven engine that delivers power through a drive shaft, everything is self-contained and doesn't require a separate generator because electricity is actually generated inside the patent-pending rotor assembly (US Publication 20110133486). The result is a compact, lightweight power source – there are no bulky generators, flywheels, alternators, fan belts, pulleys or gears to worry about. Even the starter is built-in.

Plus, the rotary generator is capable of running on a variety of low emission and carbon neutral biofuels, including propane, natural gas, ethanol, methanol and even hydrogen. And because of its design, the rotary generator is able to operate more efficiently and use less fuel than a typical piston-driven generator**.**

What makes it unique?

What makes the rotary generator unique is that the motion of the patent-pending rotor assembly is not constant. The actual motion of the rotor assembly is controlled by the energy management system and involves more complex velocity profiles, continuously changing velocities and finite accelerations to optimize fuel efficiency, control vibration and limit peak loads on the generator structure. Drawing power from the generator electromechanically allows the generator to vary the duration of the power stroke for greater thermodynamic efficiency and optimize generator performance under varying conditions of speed, load, temperature, air density, fuel ratio, etc

But it still uses hydrocarbon-based fuels. What about greenhouse gases?

Every energy storage system has trade-offs, including batteries. The key is converting stored energy as efficiently as possible and limiting greenhouse gas emissions. The rotary generator is capable of running on a variety of low emission and carbon neutral biofuels, including propane, natural gas, ethanol, methanol and even hydrogen. And because of its unique design, the rotary generator is able to operate more efficiently and use less fuel than a typical piston-driven generator**.**

Is the rotary generator a generator or a battery?

Well, in a way, it's both. It's really a compact power supply that looks and acts just like a traditional battery – inside there's a generator that runs on biofuel or hydrogen and everything is self-contained inside the 'battery' case. And just like a battery, it can be 'recharged' in a matter of seconds by swapping out a compact refillable (and recyclable) fuel cartridge. Think of the rotary generator as a powerful self-contained electromechanical battery.

But why not just use traditional batteries?

Well, the fact is that the energy density of hydrocarbon-based biofuels is over 20-30 times greater than existing battery technologies. Even at 30% conversion efficiency, hydrocarbon-based biofuels have 10 times the energy density of a battery - roughly 2.3kWh/kg vs. 0.2kWh/kg for a typical battery. As a result, devices powered by a rotary generator can be lighter, operate longer and provide greater on-demand boost power than those powered by traditional batteries. In addition, these devices can be "recharged" within seconds by swapping out a compact refillable (and recyclable) fuel cartridge and they have cycle lives many times greater than traditional batteries.

Remember as well, traditional batteries also need to be charged - often by fossil-fuel driven power plants. And, their energy conversion efficiency - that is, how much power is put in vs. how much comes back out - is much lower than many people realize, typically between 70%-80%.

And what about fuel cells?

People have been talking about fuel cells for decades, yet they remain prohibitively expensive and there's virtually no production or distribution infrastructure in place to fuel them. On the other hand, the rotary generator is based on well-established off-the-shelf technologies that are here now. If and when mainstream availability of hydrogen becomes a reality, the rotary generator needs only minor modifications to allow it to operate on hydrogen, and with zero emissions just like a fuel cell.

How can the rotary generator be more efficient than engines already out there, and doesn't it actually use more energy to generate electricity?

Because of its design, the rotary generator is able to operate more efficiently and use less fuel than a typical piston-driven generator**.** Drawing power from the generator electromechanically allows the generator to vary the speed and duration of the power stroke for greater thermodynamic efficiency and to optimize generator performance.

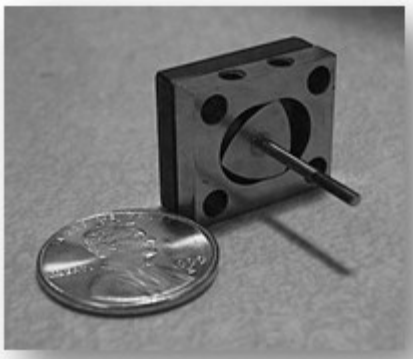
And because the only output from the rotary generator is electricity, virtually all of its mechanical energy is converted into electricity - there's no energy wasted on alternators, fan belts, pulleys and gearboxes.

Why did Clarian choose a rotary-based design? Haven't there been problems with fuel efficiency and exhaust emissions with rotary-engines?

Certainly there were issues with some of the early rotary-based designs developed in the 1960s and 1970s. However, improved spark plug and exhaust port configuration have resolved fuel efficiency and emissions issues that plagued these earlier designs. Rotary engines are actually well suited for this task because of their compact size, high power-to-weight ratio, greater volumetric efficiency, fewer moving parts and reliable operation. Today, they are commonly found in personal recreation vehicles, aircraft and unmanned drones – anywhere compact size, fuel efficient design and unparalleled reliability are required.

How big is a hybrid battery?

Because of the scalable design of the rotary generator, hybrid batteries can be virtually any size - though we expect that they will be about the size of a car battery given the existing form factor. Either way, they can be large enough to power an electric vehicle or small enough to fit in the palm of your hand, with potential to even power portable electronics. And everything is self-contained inside the rotary generator - its only output is electricity. Think of the rotary generator as a powerful self-contained hybrid electromechanical battery.



Example of a Miniaturized Rotary Engine - MEMS Rotary Internal Combustion Engine, UC Berkley

Doesn't it require an external power source that adds more weight?

Everything is self-contained within the rotary generator – there are no external storage batteries, no bulky generators, flywheels, alternators, fan belts, pulleys or gears to weigh it down. Even the starter is built-in.

How does the rotary generator keep fragile magnetic materials cool and intact during movement of the rotary piston?

The rotary generator uses a unique patent-pending thermal cooling system that maintains the temperature of the generator well within a normal operating range. Plus, the rotary generator does not use any expensive magnets – instead it uses a unique induction-based armature and reaction plate design incorporated into the patent-pending rotor assembly. And unlike a traditional piston-driven engine, the rotary generator uses a rotary piston which is more reliable and provides smoother power flow – rather than back and forth, the rotary piston spins smoothly round and round.

How is this different from the Electromagnetic Engine recently unveiled by Bill Gates?

Unlike the Gates engine which relies on a reciprocating piston and complex electromechanical valve trains and engine timing, the rotary generator has only two moving parts and there aren't any valves, providing greater reliability and more efficient power flow than the Gates engine.

In short, the Gates engine is more complicated than it needs to be – for Clarian, a rotary piston was the obvious solution.

What's more, the Gates engine is prone to catastrophic failure. With nothing to bring the engine's reciprocating piston to a halt in the event of a timing malfunction or electronics failure, the piston will literally come flying out of the engine block, destroying the engine and anything in its path. On the other hand, the rotary generator uses a rotary piston which spins safely around a fixed shaft and is virtually immune to catastrophic failure – even with a loss of compression, cooling or oil pressure, the rotary generator is able to continue producing power. And if there ever is an electronics failure, the rotary generator spins safely to a halt.

How is this different from the miniature rotary engines being developed by the MEMS Rotary Engine Power System Project at UC Berkley?

While the MEMS Project at UC Berkley also relies on a rotary engine design, their focus is really on miniaturization vs. our focus which is compact design - no matter what size the rotary generator is. What makes the Clarian design unique is that it uses a unique induction-based armature and reaction plate design incorporated into the patent-pending rotor assembly making it far more compact and lightweight than traditional generators.

Furthermore, the rotary generator is controlled by an energy management system and involves more complex velocity profiles, continuously changing velocities and finite accelerations to optimize fuel efficiency, control vibration and limit peak loads on the generator structure. Drawing power from the generator electromechanically allows the generator to vary the duration of the power stroke for greater thermodynamic efficiency and optimize generator performance under varying conditions of speed, load, temperature, air density, fuel ratio, etc.

Is the hybrid battery in production and is it available to the public?

The hybrid battery is still in the early research and development phase. Clarian is looking to partner with the public or private sector to commercialize this technology – for example, the DOE, the DOD, an energy research lab, or a vehicle or aerospace manufacturer.

How much power can a hybrid battery generate?

Because of the scalable design of the rotary generator, hybrid batteries can be built for virtually any power output – powerful enough to power an electric vehicle, or small enough to even power portable electronics.

What are the specs for Clarian's initial rotary generator prototype?

Power Output: 5kW

Displacement: 125cc

Cooling: Patent-pending air-cooling

Generator Weight: approx. 10kg, including fuel

Engine Type: Modified Sachs KM3 Wankel engine