A New Type of Fuel Cell

DOE Free Piston Thermodynamic Fuel Cell
And
EPA Hydraulic Free Piston Engine

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By Ken Galitello, Jr.

Concept investigative work done by
Peter VanBlarigan of Sandia Labs
And
EPA's hydraulic hybrid vehicle development program

As we strive to reduce fuel consumption and emissions, several technologies have emerged as a best solution. Current Proton Exchange Membrane (PEM) Fuel Cells need Hydrogen fuel, which will require a new infrastructure to create and supply Hydrogen for automotive use. A new technology, the Thermodynamic Fuel Cell, utilizes a variety of readily available combustible fuels such as gasoline, alcohol, natural gas and Hydrogen when H_2 filling stations come on line.

Combined work by the U.S. D.O.D., D.O.E, E.P.A., Universities and Business over the past 14 years has culminated in a new type of power plant. The D.O.E. calls their version a Free Piston Thermodynamic Fuel Cell. The E.P.A.'s version is a Free Piston hydraulic pump.

The DOE and EPA show both power plants have the ability of achieving 45% to 50% efficiency over conventional power plant technology of 35% efficiency, are multi fuel capable and substantially reduce emissions. Both utilize free piston internal combustion technology that is proving to be a leap in internal combustion engineering. Sandia Labs has accomplished computer modeling and fundamental experiments that show the D.O.E. Free Piston Engine possesses unique characteristics that allow for advanced thermal ability, significantly reduced friction, reduced fuel consumption and meeting Near Zero emission goals in a compact low cost power plant.

Sandia Labs states a Free Piston Thermodynamic Fuel Cell provides electrochemical fuel cell like performance that utilizes highly developed reciprocating engine technology. The ability to dynamically alter its stroke and compression ratio while the engine is running allows for a variety of

combustible fuels to be used without any changes to the engines main structure.

The Free Piston Thermodynamic Fuel Cell offers major advantages over conventional Proton Exchange Membrane Fuel Cell types in Hybrid Electric Vehicles and Online/Backup Generator Sets. When the unit is not in use, and particularly under freezing conditions, no other Fuel Cell support systems are needed to operate and require power, such as a cooling/warming system that keeps conventional Proton Exchange Membrane Fuel Cells from freezing or overheating.

Considering half of the U.S. and many other countries experience winter months where day time high temperatures are in their 30's to 40's and nighttime temps drop to teens and 20's, and in some locations –20°F overnight for a period of time. Take into account a vehicle that is driven to work, parked outside for 8+ hours under freezing or near freezing conditions or even a vehicle left out overnight. A Proton Exchange Membrane Fuel Cell would have to run a warming system to keep it from freezing and draws down Battery power. Free Piston technology in either the DOE's Thermodynamic Fuel Cell or EPA's Free Piston Engine Pump, acts like a conventional engine and needs no warming, and no power, thereby uses less energy under non use and cold conditions. The end result is less fuel usage in particular during winter months.

Proton Exchange Membrane Fuel Cell types have a startup time of minutes, while the Free Piston technology starts up and is running immediately.

Sandia Labs states that with weight being a factor, the Free Piston Thermodynamic Fuel Cell is expected to weigh significantly less than Proton Exchange Membrane Fuel Cell types. The free-piston engine develops compression and rebounds through inertial loading, therefore, the only high strength components are the piston crown and the top cylinder area. No massive rigid structure is required and there are no bearings or support structures to be damaged by high pressures or shocks. In addition, the engine components, aside from the alternator, can be constructed of lightweight materials.

Regarding cost, the Free Piston Thermodynamic Fuel Cell or the EPA's Free Piston Pump is expected to cost ½ as much as the Proton Exchange Membrane Fuel Cell due to the fact that expensive materials and support systems are not needed as much.

Regarding maintenance, the Proton Exchange Membrane Fuel Cell must have its core membrane material replaced after so many hours, like a battery, due to contamination/depletion of the membrane material, generating a recyclable waste stream and associated costs that are

expensive. The Free Piston technology requires very little maintenance for its life.

Regarding fuel types, the Proton Exchange Membrane Fuel Cell needs clean Hydrogen to operate properly. Proton Exchange Membrane Fuel Cells that run on natural gas or other carbon based fuels need an additional system to transform the fuel into Hydrogen that incorporates a loss process that requires energy and does not utilize the carbon atoms to contribute to generate electric power. The Free Piston technology runs on a variety of fuels ranging from gasoline, methanol, propane, natural gas, and hydrogen with near zero Nitric Oxide emissions and near zero unburned hydrocarbons.

DOE Sandia Labs experiments show the Free Piston Thermodynamic Fuel Cell internal combustion process is so innovative that it emits the lowest amount of CO and NOx emissions for an internal combustion engine, ever.

Using the DOE's Free Piston Thermodynamic Fuel Cell or the EPA's Free Piston Pump in Hybrid Electric and Hydrostatic Drive Vehicles allows for Multi Fuel capability, providing an alternative, competitive path to hydrogen conversion that will meet demand for economy and emissions now and in the foreseeable future.

Except for Hydrogen fuel, there are CO emissions using carbon based fuels such as Gasoline, Methanol, Natural Gas & Propane. Using such fuels in a Free Piston engine, CO emissions are substantially reduced due to the Free Piston engine operational characteristics and increased efficiency of 45% to 50% over conventional power plant technology of 35%. Natural Gas is the fuel of choice, as it has the lowest Carbon Emission property and is much more economic than Hydrogen. Natural Gas offers the best solution for short and mid term fuels. Its low Carbon content CH_4 (1 Carbon atom and 4 Hydrogen atoms) makes it the cleanest hydrocarbon fuel available, and the U.S. has an abundant supply.

The Free Piston technology:

- **Multi fuel capability important, providing an alternative, competitive path for hydrogen conversion.**
- **HCCI (Homogenous Charge Compression Ignition) combustion driven.**
- **Optimizes the thermodynamic cycle with free piston, rapid compression/expansion.**

- **Has near zero NOx(Nitric Oxide) emissions and near zero unburned hydrocarbons.**
- **Has the lowest CO emissions per power output for an internal combustion engine.**
- **Meets FreedomCAR 2010 goals for internal combustion systems operating on hydrogen or hydrocarbons.**
- **Utilizes linear alternator for compression ratio control and mechanical simplicity.**
- **Linear alternator is electromagnetic equivalent of brushless direct current permanent magnet generator, +96% efficient.**
- **Direct electrical power output.**
- **Direct pump output.**
- **Efficiency ~ 45% to 50%**
- **Emissions ~ 0**

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The folks behind the U.S. Environmental Protection Agency's hydraulic hybrid vehicle development program have been hard at work developing engines to pair up with their hydraulic hybrid transmission.

The EPA has been testing two hydraulic free-piston engines that are an outgrowth of its hydraulic hybrid programs, according to David Haugen, manager of the EPA's Technology Development Group and deputy director of the advanced technology division of the EPA's National Vehicle and Fuel Emissions Laboratory in Ann Arbor, Mich.

"When you start to examine how you want an engine to serve its function in a full-hybrid system, you realize that most traditional combustion engines are a compromise," Haugen said. "The ideal engine to propel a hybrid hydraulic transmission provides power decoupled from the wheel. It offers better fuel economy with lower emissions."

The EPA has come up with a pair of hydraulic free-piston internal combustion engines with no output shafts, so they offer direct conversion to hybrid power. Both Engine 1, a two-cylinder, two-stroke proof-of concept model, and Engine 2, a six-cylinder engine that enables four-stroke operation, use a dual-piston, opposed cylinder design. With both engines, the energy of the fuel is transformed directly into hydraulic energy by means of

a linearly moving piston assembly.

The opposed cylinder design places a combustion cylinder on either end of the stroke, with a hydraulic pumping chamber located centrally between them. The two pistons are linked in a single assembly. As the pistons move laterally, expansion occurs on one side, while the other side compresses and fuel is injected. The hydraulic pump mirrors the expansion and compression to pump oil into a high-pressure outlet and draw it in from a low-pressure inlet.

The free-piston engine allows for variable compression, flexible combustion modes, and the use of different fuels, according to Haugen. The engine can run on gasoline, clean diesel, or renewable fuels. It can burn these fuels using compression ignition diesel combustion or homogeneous charge compression ignition (HCCI).

HCCI, a relatively new combustion technology, combines elements of traditional gasoline spark ignition combustion and a diesel's compression ignition. It takes place spontaneously and homogeneously without flame propagation. In addition, HCCI is a lean combustion process. These conditions translate to a lower local flame temperature, which reduces the amount of nitrogen oxides produced in the process. NO_x is believed to be responsible for the creation of ozone.

Besides flexibility, the free-piston engine offers other advantages over traditional engines in a hydraulic hybrid setting. The free-piston engine has lower friction losses because it has no piston side loads, and lower bearing loads, making it more efficient than a standard engine, according to Haugen. It also has 40 to 60 percent fewer moving parts than a standard engine, so it should be significantly cheaper to manufacture and should offer higher reliability, he said. And, where a traditional engine is tall and requires a high hood line, these engines have a flatter profile, which would make them easier to integrate into more aerodynamic vehicle designs.

The engines are intended for use in large sport utility vehicles, full-size pickup trucks, buses, dump trucks, and delivery vehicles, where the first generation of hydraulic hybrid powertrains are targeted.

With the next generation of the engine, Haugen hopes to increase the power. The amount of power the engine can generate is a limitation of how fast it can oscillate, he said. So, engineers will work to push the engine speed higher to increase its power efficiency. The EPA is working with a private partner on this project, but that partner has requested anonymity at this time.

End of Mechanical Engineering May 2005

For Links to Technical papers, Thesis, Patents, Web sites, etc. on

- **Free-Piston Combustion Research**
- **Free-Piston Generator Sets**
- **Hydraulic Free-Piston Engines**
- **Free-Piston Pumps**
- **Free-Piston Compressors**
- **Other Free-Piston Engine Uses**

See www.free-piston-engines.com for all development of the Free Piston Linear Engine