American automakers have a dilemma: How can they reduce greenhouse gas emissions, improve fuel economy to meet newly proposed Corporate Average Fuel Economy (CAFE) standards of 40 miles per gallon and satisfy America’s insatiable appetite for bigger, faster, more powerful vehicles? Conventional solutions are costly, yield relatively small results and will take years to implement. Currently available new technologies incorporating pulsed power can help jump start a new era of less polluting fuel efficient vehicles.

A systemic approach

In the evolution of precise and efficient internal combustion spark-ignited engines (SI), a multitude of advanced strategies have been tested and implemented in a dizzying array of combinations to improve the SI 40% efficiency of energy conversion. These include lean-burn cycles, manipulated exhaust gas recirculation (EGR), variable displacement technology, variable cam timing and lift, direct injection, 7-and 8-speed transmissions, hybrid engines, alternative fuels, and others.

Changing ignition technology

Billions of dollars have been spent by automakers on improving the SI efficiency, and it may appear they’ve looked at every possibility. For example: the ignition system has undergone extensive breakthroughs over the last 50 years evolving from magnetos to points to solid state ignition and now, coil on plug. Yet, in the area of spark plugs, there has been little meaningful change in over 50 years. Electrode design and spark plug life-prolonging materials have evolved, but there’s been no increase in the actual output of the spark itself. All spark plugs for at least the last 50 years have produced less...
than 100 watts of peak ignition power, which was either assumed adequate or tolerated since there was no suitable alternative. Now there is an alternative that exponentially increases the peak power of the spark to ignite fuel more effectively and burn it more efficiently and completely.  

A drop-in solution

Pulsed power, already in use as pulse plugs for aftermarket spark plug replacements, is an enabling technology that can be used in combination with proprietary engine designs now being developed by car manufacturers. Pulsed power is the technology of energy conservation where energy is stored over a relatively long period (20 ms) of time and discharged over a relatively short period (1 ns) of time. The stored energy discharged by the pulse plug was previously wasted as heat in the current spark plug ignition system.

Pulse plugs incorporate a “pulsed circuit” into the footprint of an ISO standard spark plug. The new circuit is fully integrated into the plug and takes advantage of some old and new materials technology to “build” the circuit and improve the dielectric strength of the insulator. Because pulse plugs and spark plugs fit into the engine identically, pulse plugs could be the quickest and most cost-effective way to meet fuel economy goals, both for current models and, more importantly, for models still under development.
An expert opinion

“There is no question that this is a superior plug that will improve the ignition process. If you put the Enerpulse pulse plug in any spark-ignited engine, it enhances the ignition and provides better fuel economy. Having a plug with a capacitance of 35-50 picofarads is a huge breakthrough. It is an absolutely essential part of a lean burn system that will improve the air-fuel ratio while meeting NOx standards.”

Michael AV Ward, PhD, President Combustion Electromagnetics Inc. (CEI)

High Power Discharge

As seen below, the pulse plug discharge of over 1 megawatts completely dwarfs the discharge of an iridium-tipped spark plug producing less than 50 watts. Of note is the very large corona area completely surrounding the tip of the pulse plug, as compared to the spark plug, which has virtually none. This corona contains a very dense energy field that aids in the precision of the ignition event, ensuring ignition occurs at the same position of crank angle cycle-to-cycle.²

It is a well accepted fact that increasing the electrical power coupled to the fuel charge increases combustion quality and efficiency.³ Spark plugs, both now and when they were first invented, discharge a peak power of, at most, 50 watts. Pulse plugs discharge over 1 megawatt (10X10⁵ W) of peak ignition power without changing a single
component of the ignition system found on all spark-ignited vehicles on the road today. Pulse plugs are a true drop-in, high-power replacement for spark plugs.

**Drop-in product becomes integrated system**

Testing on current vehicles using the drop-in replacement pulse plugs (Pulstar™ by Enerpulse) has shown increases in fuel economy of up to 10%⁴ but the real opportunity lies in designing engines and engine control units (ECUs) that are optimized to take full advantage of the increased energy discharge provided. By integrating the pulse plug technology into new ignition and engine design, even greater fuel economy, as well as decreased emissions, is possible.

**More electrical power**

By matching the capacitance to the energy level of ignition, the electrical-to-plasma (energy) transfer efficiency with a pulse plug approaches 50%. This is compared to the less than 1% seen in typical automotive ignitions using spark plugs. This means 5.2 MW of peak power with a pulse plug compared to 1.25 W of peak power in a conventional ignition.⁵ Measured at Sandia National Laboratories, the peak current of a pulse plug discharge will reach over 1000a while the peak current discharge of a spark plug is less than 50 ma.⁶

As seen below, tests conducted at Southwest Research Institute show the difference in the growth of the flame front between a new iridium-tipped spark plug and the pulse plug. Using a 64,000 fps (frames per second) camera and counting pixel growth over a period of 33,321µsec, it was determined the flame kernel of the Pulstar™ pulse plug grew 60% faster than the kernel of the iridium-tipped spark plug.⁷
Combustion in lean burn environments

Pulse plugs are significantly better at igniting fuel in lean air-fuel environments than ignition strategies currently utilized by the automakers. Independent testing shows pulse plugs outperforming spark plugs in very lean air-fuel conditions. This is due to the increased size of the spark channel in combination with the very large, energy dense plasma zone surrounding the area of the spark gap. They are particularly well suited for lean-burn engines with increased percentages of exhaust gas recirculation (EGR). In addition to being useful in traditional spark-ignited engines, they are also ideal for hybrids and alternative fuel vehicles. The more difficult the ignition environment, the greater the disparity between spark plugs and pulse plugs.
Reduced cycle-to-cycle variation

Pulse plugs offer more ignition precision relative to crank angle, so they work well with direct fuel injection and other advanced engine technologies. A high current, energy dense discharge delivered in 1-2 ns (billionths of a second) produces a larger than normal flame kernel at the occurrence of the discharge. That is to say, the larger ignition kernel is created at the beginning of the ignition pulse, consistently at every cycle.

This is precision ignition as compared to ignition occurring sometime during the 100 µs (100 millionths of a second) ignition pulse, as is common in spark plug type systems. This consistency is especially important in difficult ignition environments, such as cold start, idle, transient operation and lean-burn cycles.

This pulse plug precision ignition reduces cycle-to-cycle variation in combustion pressures by up to 50%. Reducing variability in combustion pressure results in increased output from the engine, and is another manifestation of the pulse plug’s energy conservation principle.

Below are two typical dynamometer tests showing the difference between spark plugs and pulse plugs. The iridium-tipped spark plugs were brand new samples installed for the test. The pulse plugs were Pulstar model BE-1.

The implementation of pulse plugs opens up capabilities to automakers heretofore unavailable. Initiating the combustion process with more precision, and
combusting more of the presented fuel, enhances options for other areas of the fuel economy equation. Expanded opportunity now exists for electric valve phasing, cam timing, ignition timing, fuel density, fuel type, and fuel introduction. With an increase in the size of the arc channel and the very high energy dense plasma that pulse plugs discharge, freedom to expand technology choices exists throughout all engine systems, allowing the automakers greater flexibility to balance fuel efficiency, emissions and power.

Enerpulse, a privately held company headquartered in Albuquerque, NM, was founded in 1996. The company develops environmentally friendly ignition products through the application of pulsed power technology. For more information, visit www.pulstarplug.com. Contact: Louis S. Camilli at 505-999-2003 lcamilli@enerpulse.com.
References


5. Dr. C.E. Roberts and Dr. T. Alger, Spark Plug Test results, SwRI Project #03.13007, Southwest Research Institute, Feb. 2007; G.J. Rohwein, “Plasma Science”, IEEE Transactions on plasma science, Volume 25, Issue 2, Apr 1997.

6. See note 4 above.

7. Dr. C.E. Roberts and Dr. T. Alger, Spark Plug Test results, SwRI Project #03.13007, Southwest Research Institute, Feb. 2007

8. Ibid.

9. See Note 1 above.