

New Engine Technologies Could Give New Life (and Larger Markets) to Ethanol

Robert Kozak *AtlanticBiomass@aol.com*
For Advanced Biofuels USA

The Challenge

The use of E-85 (85% ethanol) fuel in “Flex-Fuel” vehicles has been limited by its 25 percent lower energy content than gasoline. When used in engines designed for only gasoline, this results in approximately 25 percent less mileage for a fuel that costs as much as gasoline. So, unless E-85 costs 70% of the price of gasoline (If gasoline is \$2.65/gallon, E-85 would have to sell at \$1.86/gallon.), there will continue to be little demand for E-85.

Engine-Design Solutions

However, new engine designs that utilize the positive ability of ethanol to resist early ignition could regain much of this fuel economy loss. Possibly even more important, these engine designs produce increased low speed power (torque) when using E-85. This torque increase could allow lower-cost E-85 engines to replace more expensive diesel engines in light-duty trucks such as the Ford F-150.

The widespread use of these engines in both automobiles and light trucks could create a US market for cellulosic E-85 in excess of that mandated by the Renewable Fuel Standard (RFS). It is very important to realize that this market would be a sustainable, rather than an artificial market, since it would be based on vehicles having equal or superior performance characteristics to gasoline or diesel powered vehicles.

Engine Design Basics

Because these new designs use some unfamiliar concepts, let's start with the basics of automotive engine operation so we can understand, and appreciate, the advantages of these new power plants.

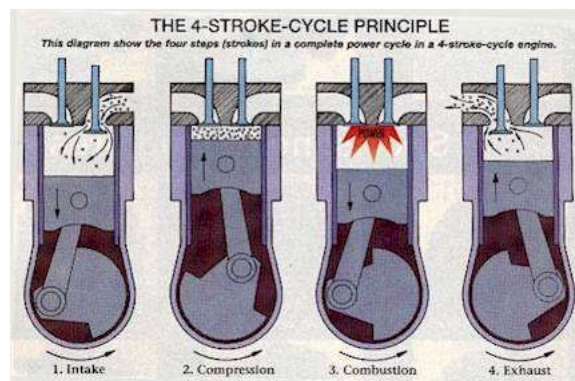
Four-Cycle Internal Combustion Engines

Automotive engines that run on gasoline and alcohol fuels are called 4-cycle spark ignition internal combustion engines. Internal combustion (IC) simply means the fuel/air mixture is combusted (burned) inside the engine's combustion chamber which is called a cylinder. A steam engine, by contrast, is an external combustion engine. Water is heated to produce steam in an external boiler and is then injected into the cylinder.

Four-cycle engines require the piston to go up and down twice in the cylinder to produce one power stroke. The four cycles (strokes) are:

- 1) intake-piston goes down,
- 2) compression-piston up,
- 3) power-piston down, and
- 4) exhaust-piston up.

Four-cycle engines also use “poppet” valves at the top of the cylinder to regulate the flow of intake and exhaust fuel/air mixtures. This type of engine is also called an “**Otto Cycle**” engine named after Nicolaus August Otto its German inventor. There are also two-cycle engines, that do not have such valves, but we'll get into them in a future article.



Spark ignition means the fuel/air mixture is ignited by an electric charge. This requires a complex ignition system that can fire a sparkplug at exactly the right time (a millisecond makes all the difference) no matter the varying operating conditions.

This design also allows for lighter weight, less-expensive engine construction than required for diesel engines where the mixture is ignited by compression. Compression ignition requires much stronger and heavier cylinder wall construction to withstand the higher compression. This means diesel engines are much heavier and much more expensive to build.

Hence, if a lighter and less-expensive E-85 spark ignition engine could produce the same low-end power with comparable fuel economy as a diesel, a car company would soon produce it to improve their bottom-line.

Ethanol, Octane, and Engine Efficiency

Thermal Efficiency The absolute goal of all engine design is to extract the maximum amount of energy contained in the fuel delivered to the combustion chamber. This is called thermal efficiency. However, this thermal efficiency goal is restricted by two realities: 1), the economics and technology of engine construction, and 2) the characteristics of the fuel being used.

The fact that automotive engines have to be both light weight and inexpensive to build is pretty straightforward, producing near perfect thermal efficiency in an engine that weighed two tons and cost \$1 million dollars to build would be worthless in the automotive industry.

The effects of fuel composition are probably not as easy to understand. But let's give it a try.

Thermal efficiency rises with the compression ratio achieved in the compression stroke. Near ideal efficiency occurs when the ratio between the volume of the cylinder when the intake valve closes at the bottom of the compression stroke and the volume when the piston reaches the top is 17:1. This means the volume of the fuel and air is compressed 17 times.

Octane Does your car or gasoline powered truck have a compression ratio this high? No. Why not? The gasoline that comes out of the

nozzle at the local Exxon or Shell explodes spontaneously way before that type of compression is reached. If you'd look at the specification of the engine you'd most likely see a compression ratio in the range of 9-10.

This spontaneous combustion caused by extreme pressure is called by several different names: pre-ignition, dieseling (because it acts like a diesel), or knocking, because that's what it sounds like. What happens is that the fuel/air mixture ignites while the piston is still moving up on the compression stroke. The resulting flame front pushes down against the onrushing piston causing the piston to shudder and, in extreme cases, to break.

Automotive and fuel engineers have devised a measurement for a fuel's ability to resist pre-ignition, it's called the Octane Rating. Regular gasoline has a rating of 87 while "high-test" has a rating of 91-93.

By now you're asking, does any readily available and relatively inexpensive fuel exist that has an octane rating high enough to allow high compression ratios? Well yes. Alcohols do. E-85 has an effective octane rating of above 100. This would allow compression ratios in the 13+ range.

And you're probably also asking, why not build an engine that could benefit from this? Again, that would be relatively easy, if, and this is one huge IF, you used E-85 100% of the time. If, however, you ever used straight gasoline or E-10, the much lower octane would result in engine damage.

So, we know automotive engineers can design and build engines that maximize the performance of either gasoline or alcohols. We also know current "Flex-Fuel" engines are actually engines designed to maximize gasoline performance and not that of E-85. And that leaves us with the question of the decade:

Can automotive engineers design and build engines that maximize the performance of BOTH gasoline and alcohols?

The answer is yes!

New Multifuel Engine Designs

From what you've read thus far, this "yes" answer would seem to involve a design that could vary the compression ratio based on the amount of ethanol in the fuel. In addition, the design should also maximize the thermal efficiency possible from a compression ratio in the 12-13:1 range. Can these two objectives be met at the same time?

Fortunately, by combining the current generation of computer engine controls involving multiple sensors and actuators, advances in fuel injection and turbocharging technology, and some previously overlooked historical engine designs, these goals can be simultaneously met.

Step One: Maximizing Thermal Efficiency, The Atkinson Cycle

A late 19th century English engine pioneer, James Atkinson, realized that to maximize thermal efficiency in an IC engine the power stroke had to have more time for combustion than for compression. His solution was a complex crankshaft system that produced a shorter compression stroke and a longer power stroke with the same length piston rod. Although used in custom applications, this asymmetrical mechanical solution was never mass produced.

Now, however, both Toyota and Ford are applying this Atkinson concept in their hybrid IC gasoline engines. Instead of a complex crankshaft though, through computer controls both manufacturers delay the closing of the intake "poppet" valves to create a shorter period of time for the compression stroke as compared to the power stroke. While this increases thermal efficiency through a longer period of combustion, it also decreases the available power since by decreasing the compression stroke, the size of

the engine is actually smaller than if Otto Cycle valve timing was used. In a hybrid application this loss of power is compensated for with an electric motor. Also, the Atkinson cycle is not really advantageous for alcohol fuels since very high compression ratios are not possible.

Step Two: Gaining Back Power: The Miller Cycle

In the 1920s an American racing engine builder and designer Ralph Miller overcame the power deficiencies of the Atkinson cycle engine by adding a supercharger to the intake system. The supercharger increased the pressure of the air/fuel mixture coming into the cylinder during the shortened Atkinson compression stroke to several times atmospheric pressure. This raised the amount of fuel and air available for combustion thereby increasing power and thermal efficiency.

Since Miller was controlling all this mechanically (including the valve timing), maintaining peak efficiency was virtually impossible. So, while Miller engines were very successful and won several Indy 500s, they were not suited to production cars.

Step Three: Putting It All Together: The Eco-Boost Engine

Starting in 2009, Ford Motor started putting something called Eco-Boost engines in their cars. These small displacement mass-produced engines are generating over 100 horsepower (hp) per liter (61 inches³), a value reserved for expensive racing engines, with good fuel economy. These figures show high thermal efficiency as well as a smooth, consistent burn that translate into increased torque (power).



The 1.6L Ford Eco-Boost Engine

These Ford engines combine two sequential turbochargers (driven by exhaust heat thereby reusing waste combustion energy) that maintain elevated intake pressure at all engine speeds with a “direct” fuel injection system that sprays fuel into the combustion chamber at the very last millisecond to help avoid pre-ignition. The engine also has variable intake and exhaust timing to vary compression and power strokes. The entire system is controlled by computer with sensors measuring both intake and exhaust pressures and temperatures. Essentially, it is the modern application of a combined Atkinson/Miller engine.

While Ford is currently using the engines only in cars or SUV applications, the author heard “unofficially” from a Ford official that an Eco-Boost engine will soon be used in some Ford F-150 pickups.

As for use of the engine with E-85, the author also heard “unofficially” from Ford engineers that it had been tested with E-85 and produced good power.

As I think you can see, “Eco-Boost” type technology would produce a very efficient “Flex-Fuel” engine.

Step Four: A 2nd Generation “Eco-Boost” Truck Engine: The Ricardo EBDI Ethanol Boosted Direct Injection (EBDI) Engine

At the Washington DC 2010 Auto Show, Growth Energy and Ricardo Engineering introduced a V-6 engine of about 3.5L in size that could replace a 6.2L gas or diesel engine in a standard GMC Sierra 3500 pick-up truck. The engine uses sequential turbochargers, direct injection, and a computer controlled engine management system to maximize power and fuel mileage from fuels ranging from straight gasoline to E-85. The engineering director for Ricardo referred to this engine as a 2nd generation eco-boost type engine.



Kent Niederhofer, President of Ricardo, Inc. (left), and Gen. Wesley Clark, Co-Chairman of Growth Energy, take a look at the Ricardo EBDI Engine

Getting Back Fuel Economy With E-85: Thermal Efficiency and Fuel Mileage

Well, the engine technology is quickly becoming available and the power that will be available is probably getting the gearheads out there excited. But one little issue remains: Will these engines get back any fuel mileage? Ricardo has said mileage with E-85 should be within 90% of straight gasoline with their engine. The rightful question should be then, how is this possible if the energy content of E-85 is 24% less?

Comparison of Fuel Energy Values (In British Thermal Units: BTU)

BTU information from US EIA/DOE

Fuel	BTUs/Gallon	Percent
Gasoline	124,000	100%
E-10	120,280	97%
E-85	94,190	76%

Remember Thermal Efficiency? To start with, no internal combustion engine can convert all the energy contained in the fuel to power at the drive wheels. Friction, the power needed to turn the crankshaft on non-power strokes, the limits of metallurgy, and the composition of the fuel, among other reasons means excess heat as well as exhaust gases come out of the cylinders.

Recall the hot exhaust gases that power the eco-boost and Ricardo turbochargers? This means not all the energy in a gallon of fuel is actually converted into power that drives a vehicle down the road.

Taking Advantage of E-85's High Octane

These two new engines just described are able to use the higher octane value of E-85 to produce higher thermal efficiencies as well as increased power.

For example, a reasonable limit of engine (not total vehicle) thermal efficiency for 87 octane gasoline in an eco-boost application would be about 45%. This translates into 55,800 BTUs (124,000 BTUs x .45) for power and the rest resulting in waste heat.

The 100+ octane rating of E-85 would be expected to produce approximately a 10-15% increase in thermal efficiency. At 57.5% (a 12.5% increase) efficiency E-85 would produce 54,159 BTUs (94,190 BTUs x .575) for power or 93% of that produced from straight gasoline.

A Bright Future

This might read like black magic, or maybe alchemy, but it's actually a combination of science and very smart engineering.

If there is enough encouragement from the ethanol industry and the motoring public, the future of E-85 could be very bright. And it would be a future driven not by subsidies but by great vehicles getting both excellent performance and fuel economy.