



New Engine Technologies Could Produce Similar Mileage for All Ethanol Fuel Mixtures

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(Updated Version: August 2012)

The use of higher ethanol blended (30% ethanol and above) 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 ethanol costs 75% of the price of gasoline (If gasoline is \$2.65/gallon, E-85 would have to sell at \$1.99/gallon) there will continue to be little demand for E-30 and higher ethanol content.

However, new engine designs that utilize the positive ability of ethanol to resist early ignition could regain much of this fuel economy loss. Even more important, these engine designs produce increased low speed power (torque) when using E-30 or higher blends. This torque increase will allow lower-cost 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 ethanol 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.

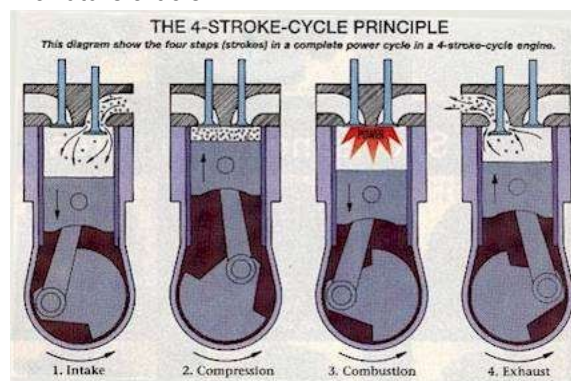
Because these new designs use some unfamiliar concepts, let's start with the basics of automotive engine operation so we can

understand, and appreciate, the advantages of these new power plants.

Engine Design Basics

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 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 referred to as 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. But this design also allows for lighter weight, less-expensive engine construction than required for diesels 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-30+ 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

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.

However, 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.

Does your car or gasoline powered truck have a compression ratio this high? No. Why? 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 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. Ethanol 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 a higher ethanol blend 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-30 or higher. 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. Needless to say, this asymmetrical mechanical solution was never mass produced.

However, both Toyota and Ford are now applying this Atkinson concept in their hybrid IC gasoline engines. Instead of a complex crankshaft though, 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 Ecoboost™ and Ecotec™ Engines

Starting in 2009, Ford Motor started putting something called the Eco-Boost engine 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 EcoBoost 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.

As of 2012, the EcoBoost is quickly becoming Ford’s primary engine technology. A 3.5L V-6 version is seeing wide acceptance (over 40% of total sales) in the Ford F-150 pickup. A four-cylinder 2.0L model will be available in the 2013 Focus ST and Ford Fusion. And , a very small three cylinder version is being produced that will power Fiesta sized models.

GM has also begun to market similar engine technology they call Ecotec. It too has the combination of variable valve timing, turbocharging and direct fuel injection. A 2.0L version is available in the Buick LaCrosse and Regal models while the Chevy Cruze offers a 1.4L version. In the case of the Buick Regal, GM is offering an E-85 Flex-Fuel version. (NOTE: EPA mileage estimates were not available for E-85 use at press time.)

These exciting engine developments really say that Flex-Fuel vehicles that can get similar fuel economy on E-10 or E-85 fuels are just around the corner. The question is, how can they do that?

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

With Eco-Boost and Eco-Tec engine technologies quickly becoming available, the power that will be available is probably getting the gearheads out there excited. But will these

engines get back any fuel mileage when run on E-85? And, 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%

Thermal Efficiency is the KEY

To start, remember one thing. No internal combustion engine can convert all the energy contained in the fuel to power at the drive wheels. Friction between moving parts, the power needed to turn the crankshaft on non-power strokes, the limits of metallurgy, among other reasons, creates “waste” heat energy as well as exhaust gas hydrocarbons (unburned fuel) coming out of the cylinders. Recall the hot exhaust gases that power the EcoBoost and Ecotec turbochargers? That was a use of “waste energy” to create more power.

This means not all the energy in a gallon of fuel is actually converted into power that drives a vehicle down the road. For example, a reasonable value of engine (not total vehicle) thermal efficiency for 87 octane gasoline in an eco-boost/ecotec application would be about 33%. This translates into 40,920 BTUs (124,000 BTUs x .33) available per gallon to power a vehicle with the rest being waste heat or fuel.

But what could an ecoBoost or ecotec engine do with E-30 or higher? Remember the higher octane? With the 100+ octane rating of E-30, a properly programmed ecoBoost/ecotec engine would be expected to produce up to a 10% increase in thermal efficiency. At 41% (an 8% increase) E-30 would produce about 38,618 BTUs (94,190 BTUs x .41) for power. This is about **94%** of that produced from straight gasoline and **97%** of that produced from E-10.

Comparison of "Power" BTUs Produced

Fuel	BTUs/ Gallon	Thermal Efficiency	"Power" BTUs
87 Octane	124,000	33%	40,920
E-10	120,280	33%	39,692
E-30 (or higher)	94,190	41%	38,618

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, the Federal government, and the motoring public, motorists would be able to get about the same mileage no matter what ethanol/gasoline mixture they use.

Optimal ethanol mixtures could then be driven by the relative market prices of ethanol and gasoline. For the motorist it wouldn't matter since mileage and performance would be about the same.

This bright future is even greater since it would not be driven by vehicle purchase or fuel subsidies, but instead by great technology combined with the marketplace.

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