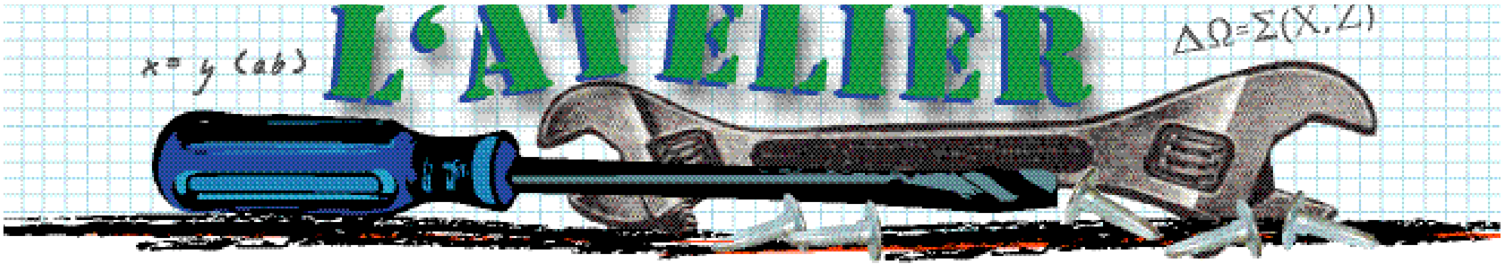


E-TEC : Clean, economical, friendly.... two-stroke?!?

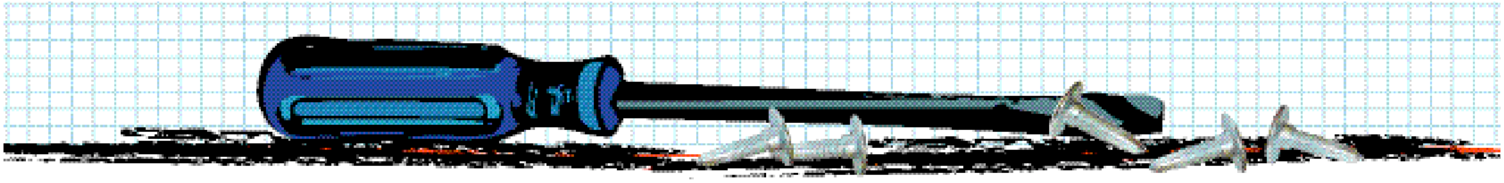
By Michel Garneau

Let's face it, industry pundits, environmental extremists and indeed an increasing number of snowmobilers it seems, have been predicting the demise of the two-stroke engine for some time now. After all, how could an engine design that actually burns its oil ever hope to meet forthcoming exhaust emissions standards? Everyone knows that two-strokes are smoky, smelly and unreliable beasts that will surely go the way of the dinosaur, they claim with some amount of self-assurance and glee. Are they right?

Direct injection 101

In recent years snowmobilers have become familiar with the basic concept of cleaner-burning injected two-strokes. By this we do not mean more traditional throttle body type injection systems such as the BEFI system used by Arctic Cat (wherein the injector is basically a replacement for the carburetor) but rather the so-called "semi-direct" injection systems first used by Ski-Doo in their 2-TEC and subsequently Polaris in their Cleanfire engines. In these applications, air alone is introduced into the engine via the normal intake channel with fuel being injected into the cylinder by injectors (mounted in or near the transfer port) at the last possible instance before port closing thereby reducing significantly the loss of unburned gas out the exhaust, the traditional weakness of conventional two stroke engines. These designs clean up the emissions (particularly unburned hydrocarbons) to the point that the powerplants equipped with such systems can be made to comply with current EPA standards (or, more accurately, make a "positive" contribution to the fleet compliance of their respective manufacturers' line-up). However, whether these semi-direct designs can meet the more stringent standards set to be introduced after 2010 remains to be seen. Does this, then, spell doom for the two-stroke as many would have you believe?

Not quite. Enter direct injection. In this variation, fuel is injected into the cylinder once the exhaust port is fully closed. This means that there can be no escape of unburned fuel out the exhaust. The end result, in theory, is an engine that keeps virtually all of the two-stroke's traditional strengths (namely relative simplicity, light weight, reduced friction and manufacturing cost, low maintenance requirements and high power production) while being extremely clean-burning and energy efficient. Why then, you ask, don't we see more DI engines in motorized products? There are many reasons although most are related to a lack of development. In essence, most of the engine-related development dollars have gone into four-stroke engines, the powerplant of choice for automobiles. This obviously has benefited their development in other fields, including snowmobiles, but at the detriment of other engines types (including diesels). One case in point is the technological/hardware constraint

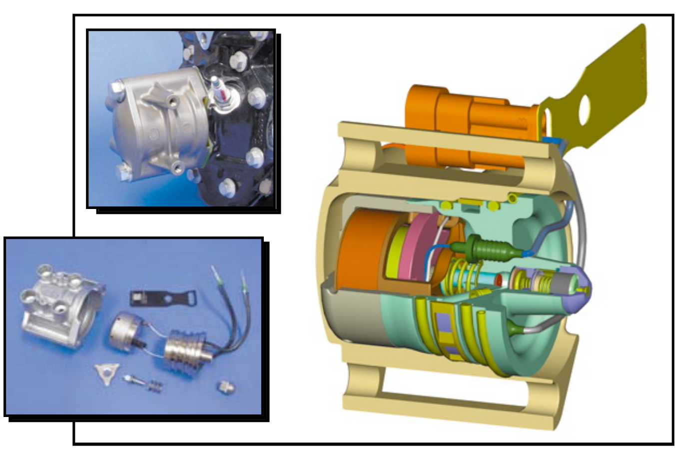


in terms of available injector technology. In effect, a DI engine requires that the fuel be injected into the cylinder only after the piston has closed off the exhaust port yet before the spark plug fires. For illustration purposes think TDC but, in practical terms it must be before this due to ignition advance (which, to compound matters, increases as rpm rises in order to provide sufficient time for the flame to travel and burn all of the trapped fuel/air mix). Therefore, injection time gets “squeezed” by two factors, piston (or engine) speed and increasing ignition advance. It stands to reason, then, that building a DI engine capable of generating the kind of rpm needed to produce decent power requires a very fast and accurate injection system.

Fixing the Ficht: from speaker to injector

The original direct injection Evinrude Ficht engines, while a significant step forward compared to traditional two-strokes, experienced teething problems, namely reliability issues and noisy injectors. They were also handicapped by relatively low rpm ceiling of about 6500 rpm dictated by the limited ability of the injectors to do their work in the very short timeframe available above this engine speed. The solution, then, to building a better DI engine lay in the development of a more rapid, quiet, versatile and efficient injector.

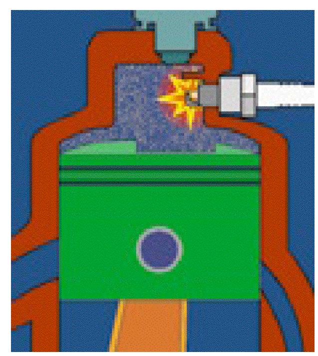
Enter the E-TEC. Its heart is a new high-tech patented injector (one of the many patented components in the engine) which delivers its fuel charge in one-half the time of traditional DI units. While the Ficht’s injector operated on the basis of a mobile iron core in an electrical solenoid, the new E-TEC unit uses a principle familiar to audiophiles. In essence, the driver is a “voice coil” or lightweight coil of wire that is free to move axially (back and forth). It is located in the annular gap of a powerful magnet and is



driven back and forth by the change in polarity created from a current pulse (ie. Opposite poles attract, like poles repel). The low inertia makes for rapid response time and allows it to operate at speeds up to 10,000 rpm (in tests). This also enables the injector to deliver more fuel in a shorter injection pulse.

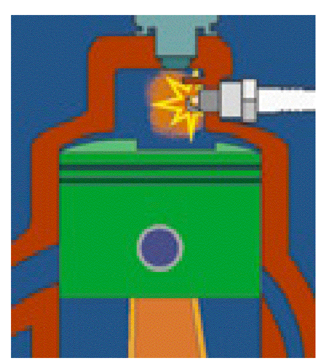
Will that be stratified or homogeneous?

Stratified? Homogeneous? Huh? These concepts are really quite simple so let’s begin with something we already know and are familiar with: homogeneous charge. This refers to a uniform (or homogeneous) air-fuel mixture typically found in internal combustion engines, be they carbureted or fuel injected. It means, essentially, that the microscopic fuel droplets are spread evenly throughout the air found in the cylinder. It burns efficiently as the fuel droplets, being so small in size, expose a maximum area to the surrounding oxygen molecules, thereby ensuring a better and more complete burn. And, as we all know, a more efficient and complete burn means more power and fewer emissions. This charge type has been shown to be ideal for medium to high load conditions and speeds.



Homogeneous charge

If a homogeneous charge is a uniform mixture, a stratified (or non-homogeneous) charge is the opposite. In other words, the fuel and air are not perfectly mixed. In the case of the E-TEC, a stratified charge, then, is one in which the fuel droplets are not evenly distributed through the air in the cylinder and this is a key component of the E-TEC’s success.



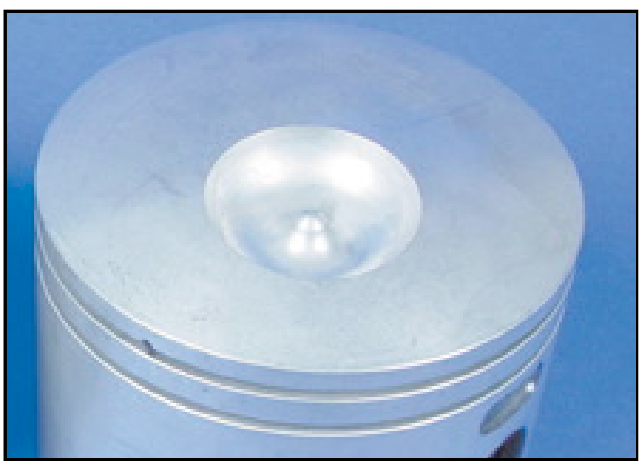
Stratified charge

In this case, in low load and low rpm operation, the fuel is injected in relatively large droplets in close proximity of the spark plug electrode at the very instant that the sparks occur (“spray-guided combustion”).

Injector position in the combustion chamber. Please note that the spark plug gap is indexed in the direction of the injector nozzle (to ensure a more efficient combustion in stratified mode.)

This charge type provides a lot of clean air for better burning and allows ultra-lean mixtures to be used (60:1 air-fuel ratio as opposed to the more typical 15:1). The results are more complete combustion (lower CO emissions), fewer unburned gases (lower HC emissions), smoother idle (no rpm hunting or fluctuation typically associated with two-stroke engines), and optimized fuel efficiency.

The E-TEC has some unique components and abilities which permit it to operate in stratified mode. For example, the pistons come with a special “re-entrance splash point” cast into the piston crown which helps to amplify stratification at low-rpm by redirecting fuel charge to the spark plug for optimized combustion.

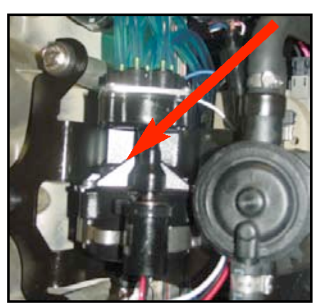


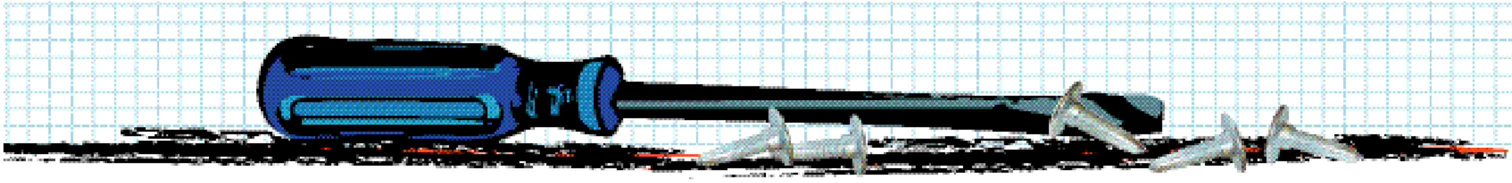
Also, the E-TEC system senses when to change the number of droplets going into the chamber (depending on the engine’s needs) and is capable of varying the size of these (for example providing for larger drops to cool the hot piston crown) which makes for exceptional fuel efficiency and reliability. Finally, as it is not desirable for the engine to operate continually in stratified mode, the injector design is unique in allowing the flexibility to alter between it and homogeneous mode. What, then, is the exact changeover point? Actually, engineers like to refer to a changeover zone more so than a point as the engine’s Electronic Management Module (EMM) sets the exact changeover based on throttle position and engine load (calculated by comparing rpm with throttle position) although it typically occurs around 3000 rpm.

The ABC’s of E-TEC

The E-TEC has many innovative features, some dictated by the engine design, others developed to increase reliability or facilitate ownership. Lubrication duties are handled by the E-TEC auto lube oiling system that eliminates the mixing of oil and fuel, nothing revolutionary there. However, due to their combination of targeted oil delivery system, pass-through connecting rod lubrication (photo: E-TEC-rod) and electronic oil pump, E-TEC engines have a lower oil consumption than previous DI engines (50% less) or conventional two-strokes (75% less).

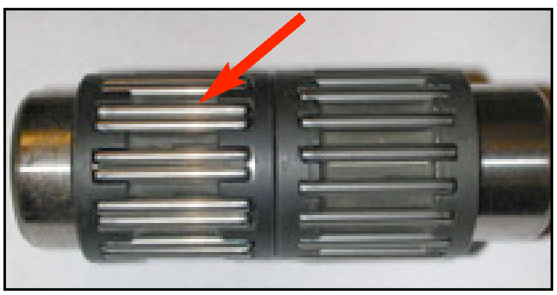
The use of an electronic pump also allows the oil feed rate to be programmed according to the oil type used. For example, an engine that will run exclusively on fully synthetic oil can have its pump reprogrammed such that it will use only 50% of what it would with strictly mineral oil. This dramatically reduced oil supply, along with the remarkably efficient combustion characteristics, result in an engine that is smoke-free and as clean or cleaner than a comparable four-stroke. Remember that oil (like gasoline) is a hydrocarbon and when fully burned generates CO_2 and water vapour (same by-products as gasoline combustion). Most two-strokes smoke because they cannot generate the necessary combustion conditions to provide a complete burn of the oil but the advanced E-TEC engine can and so does not generate any smoke.



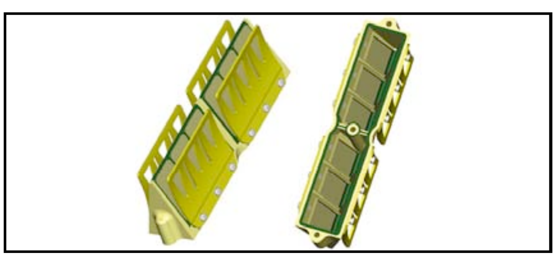


Bombardier incorporated an improved full skirt piston design that decreases the "piston slap" sound found in typical four-strokes (product of their lighter skirt-less piston design). They didn't stop there, however, as they elected to build them from a special aluminium-silicon casting alloy known as MSFC-398 (developed by NASA). This alloy, whose properties are virtually indistinguishable from regular alloys at room temperature, is nearly three times stronger at operating temperature. Its molecular structure, which includes numerous very hard silicon particles, is more resistant to the typical movement of layers of metal atoms slipping past each other.

The pistons also feature a two ring design for better sealing and cooling (heat transfer). Finally, caged double roller bearings (featuring a pair of rollers per cage opening resulting in a 30% higher load capacity than regular single roller caged bearings) are used for better durability and longevity.



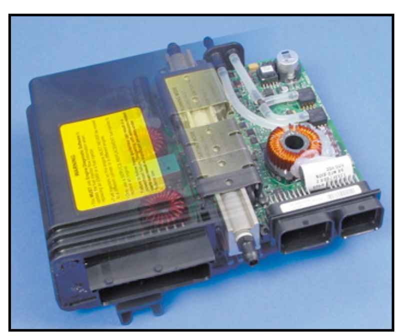
The cylinder bores, meanwhile, are made of iron and undergo a boron nitrate cylinder honing process. This helps to prevent the metal from folding over during honing. The end result is the exposure of graphite pockets in the iron which provide better oil retention, hence improved lubrication. On the intake side, the engines use a case reed design featuring massive 12 petal reed blocks for impressive air flow and response. The reeds themselves are made of stainless steel and are housed on rubber-coated blocks for long-term durability.



To ensure quick and reliable starting every time, E-TEC engines fire up in stratified mode and feature a "sure start system" designed to start within one revolution. To achieve this, the EMM delivers not only higher voltage (and hence a hotter spark) but also more frequent sparks (by virtue of its multi-spark capacity) to guarantee an instant start that is free of the traditional "wetdown" (meaning basically flooding the engine with fuel until the cylinder is wet and the mixture lights) period. As an added bonus, the start is much cleaner (less pollution and smoke) than is possible with a non-stratified engine. Once running, the idle control circuit takes over and carefully regulates the fuel feed to ensure a smooth and consistent idle. While this sounds very usual it is anything but. In a normal (non-stratified) engine, the air-fuel mixture must remain a constant 15:1 so adding more fuel automatically means adding more air and vice versa. In a stratified engine, fuel delivery and air entry volume are independent of each other. In effect, an E-TEC engine could run without a throttle plate or butterfly as the determining factor for engine rpm is not the amount of air entering the engine but rather the amount of fuel being delivered. Therefore, regardless of throttle opening, engine speed will always be set by the fuel quantity. Want to raise idle speed? Feed it more fuel. Want to lower it? Reduce fuel supply. As you can see then, the EMM can easily and precisely regulate idle rpm by varying only the injectors' action, resulting in unrivalled levels of idling smoothness.

Moving on to the cooling system, DI and SDI two-strokes face a special challenge in terms of crankcase cooling. Unlike a typical two–stroke which relies to some degree on fuel entering the crankcase for cooling, DI and SDI engines take in only air and so must rely on other sources of cooling. This issue was solved by going to a liquid-cooled crankcase.

We have already touched on some of the EMM's numerous functions and will now continue our examination of this remarkable processing unit. To begin with, its construction is unique as it uses a special 10 layer construction circuit board which allows it to process both high-current and low voltage signals, something previously unheard of. To say it is the brain of the E-TEC is an understatement as it controls all of the following components/circuits/parameters: ignition (both the timing curve as well as the strength and number of sparks delivered by the multi-spark discharge system), fuel injection (both timing and quantity), alternator and charging circuit, oil pump, fuel pump, gauges (use of a Controlled Area Network enables all engine operating parameters to be read on external gauges), and water injection system (injects water



into the exhaust stream to change the gas temperature and hence alter the power curve characteritics) on selected models. Now, as you can imagine, managing all of these tasks takes input and here again the list is substantial: engine rpm, throttle position, crankshaft position (accurate within 1 degree!), exhaust back-pressure (since exhaust outlet is submerged), atmospheric pressure, battery voltage, oil system (both level and pressure), engine and cylinder head temperatures, ignition key position, and even its own internal temperature! As if this wasn't enough, Evinrude engineers have graced the EMM with many interesting features including the ability to store and keep all data even if the battery is unplugged. Another is the inclusion of an auto-storage feature which injects oil into the cylinders and shuts off the ignition making storage an inexpensive and simple proposition for the owner. Also, in order to protect the engine in the event of an absence of oil or lubrication system failure, a special SAFE (Speed Adjusting Failsafe Electronics) mode allows the engine to run up to ten hours at limited rpm. This ingenious feature will not only allow you to get home but also prevent expensive damage to critical components.

The EMM also provides the owner with a hassle-free or seamless break-in procedure by automatically upping the oil supply in the first hours of operation. The computer, by tracking the hours and conditions of operation, will automatically re-set the oil feed to the normal rate once sufficient operating time has occurred. Finally, a digital diagnostic panel monitors the engine and user-friendly lights notify the owner of any system checks.

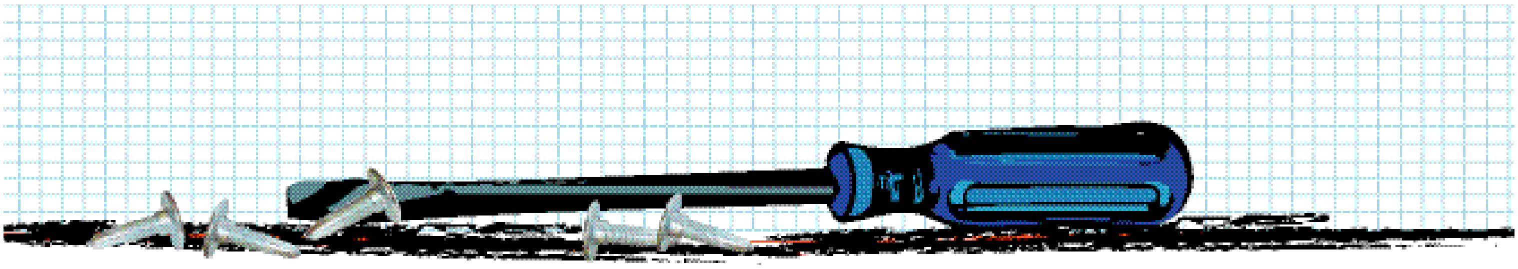
Affordable and simplified maintenance were also key objectives of the E-TEC design team. Maintenance costs can add up quickly and in this regard the E-TEC has a distinct and noticeable advantage over its four-stroke competitors. As mentioned earlier, auto-storage means no dealer winterization or spring tune-up. Also, there are no belts, valves, cams, or mechanized oil pumps to service or replace. Furthermore, the oil doesn't need to be changed, providing added savings on oil changes and filters. A new double platinum spark plug design is meant to last 300 hours before needing replacement.

Both the intake and exhaust circuits have been equipped with special Heimholtz resonators. These are essentially specifically tuned sound chambers designed to reduce the sound emissions at certain key frequencies, resulting in a quieter engine.

The end result of this effort is an engine that is as quiet as competing four-strokes. Still on the exhaust side, present E-TEC engines do not come equipped with variable exhaust height technology (ie. RAVE valves) yet this is surely being looked at as an option for the future.

The hard data

Emissions data clearly proves that the E-TEC is an overwhelming success. To begin with, it complies with 2006 EPA, European Union (EU), and 2008 California Air Resources Board (CARB) 3-Star ultra-low emissions standards for outboard engines. The E-TEC has also been recognized by CARB as being the Best Available Technology, high praise indeed given the CARB's long-held disdain for anything two-stroke. Also, the E-TEC is the first and only outboard engine to win the prestigious (US) EPA Clean Air Excellence Award. Data provided by BRP indicates that the E-TEC's carbon monoxide (a toxic gas) emissions are typically 30 to 50 percent lower than a similar four-stroke engine and, at idle, are lower by a factor of 50 to 100 times, a not insignificant amount! Furthermore, the



sealed fuel system minimizes evaporative emissions. Finally, BRP claim that combustion temperature is, on average, about 25 deg. C lower than in a conventional carbureted two-stroke. This should translate into even lower oxides of nitrogen (NOx, a main component of smog) emissions, an area in which two-strokes already have a sizeable advantage over four-strokes.

In terms of fuel consumption, published tests clearly indicate that the E-TEC is at least as efficient as competing four-strokes. This should hardly come as a surprise to our readers as Kevin Cameron (in last month's Atelier) clearly stated that a direct injection two-stroke can attain fuel consumption figures that are equal or even superior to four-strokes. Reports from satisfied owners also support this fact.

One area where two-strokes generally fall short of four-strokes is in smoothness, especially at low speeds (mostly idle). Here again the E-TEC rewrites the rules. Idling smoothness can be measured using a unit known as covariance of indicated mean effective pressure (cov of IMEP). In layman's terms, it measures the variance in cylinder pressure (or combustion cycles) over time. This data can be used to trace the pattern of an individual cylinder over a given time span or to compare two or more cylinders. A typical two-stroke has a cov of IMEP of over 30% (an indication of great variability between combustion cycles hence the relatively unstable idling rpm) whereas four-stroke are generally much smoother with a rating of about 10%. The E-TEC, on the other hand, typically has readings in the area of 5% ! This means that there is very little variation between each individual cylinder power stroke, the recipe for a smooth engine.

Popular wisdom states that four-strokes have flat torque curves whereas two-strokes are peaky. When discussing this notion with Evinrude engineers we were told that the problem with this theory is that generally four-strokes that are called on to compete with two-strokes have the luxury of having a sizeable displacement advantage (ranging generally from 40 to 100%). In essence, what you are left with is a small highly tuned two-stroke (with a peaky power curve) being compared to a mildly tuned much larger four-stroke (and its flat torque curve). When the two engines are tuned for similar specific outputs (measured in hp/litre), we are told that the two-stroke has a significant advantage over the four-stroke at all engine speeds, particularly in the mid-range.

One final point to consider is the issue of what happens to the oil. In the case of the E-TEC, it burns its oil meaning that the environmental impact of this process (ie. combustion of the oil) is measured and taken into account in its measured emissions readings. In the case of the four-strokes, however, things are not so clear. Most of the recuperated oil from four-stroke engines ends up being used for industrial purposes and oftentimes is burned in the process. The problem lies in the fact that, unlike two-stroke oil, four-stroke is not designed or formulated to be burned. Burning four-stroke oil results in the discharging of heavy metals and other contaminants (additives) into the atmosphere, hardly a desirable outcome. It should be said that this applies to all four-stroke engine oil (including that used in your automobile, lawnmower, ...) not only that used in snowmobiles and boat motors.

Coming soon to a dealer near you?

"So when can I buy one of these E-TECs in a snowmobile?", you ask. Well, we asked this very question to numerous individuals at Ski-Doo (including upper management) and were greeted with non-committal and evasive smiles. Of course, unlike boat motors which typically operate in a relatively narrow temperature range and always above the freezing point, snowmobiles can be called on to operate in extreme (read: cold!) temperatures and dealing with this factor may be proving to be a problem although, yet again, everyone is tight-lipped on the matter.

What do we think? Well, from a business (and return on investment) standpoint, it is extremely unlikely that BRP will sit on this technology and limit it to outboard motor use, especially when it offers so much potential for snowmobile (and other) use. For this reason, we expect to see an E-TEC powered sled on dealer floors in the not-too-distant future. If temperature is indeed an obstacle, remember that it was only a few short years ago that dreams of building a 10,000 rpm DI engine seemed unrealistic and indications are that BRP have tested running models of just such engines using the new injectors. In the end, technology and market forces will determine just how soon before you can run down to your dealer to purchase your very own E-TEC Ski-Doo but the smart money is on sooner rather than later.

So, is the two-stroke dead? Evidently not.

Next issue : We will be taking a look at the Clean Snowmobile Challenge, an annual inter-collegiate competition that pits various North American universities against one another in a race to build a cleaner, quieter snowmobile all the while maintaining respectable performance levels. See what our future engineers have in store for us.