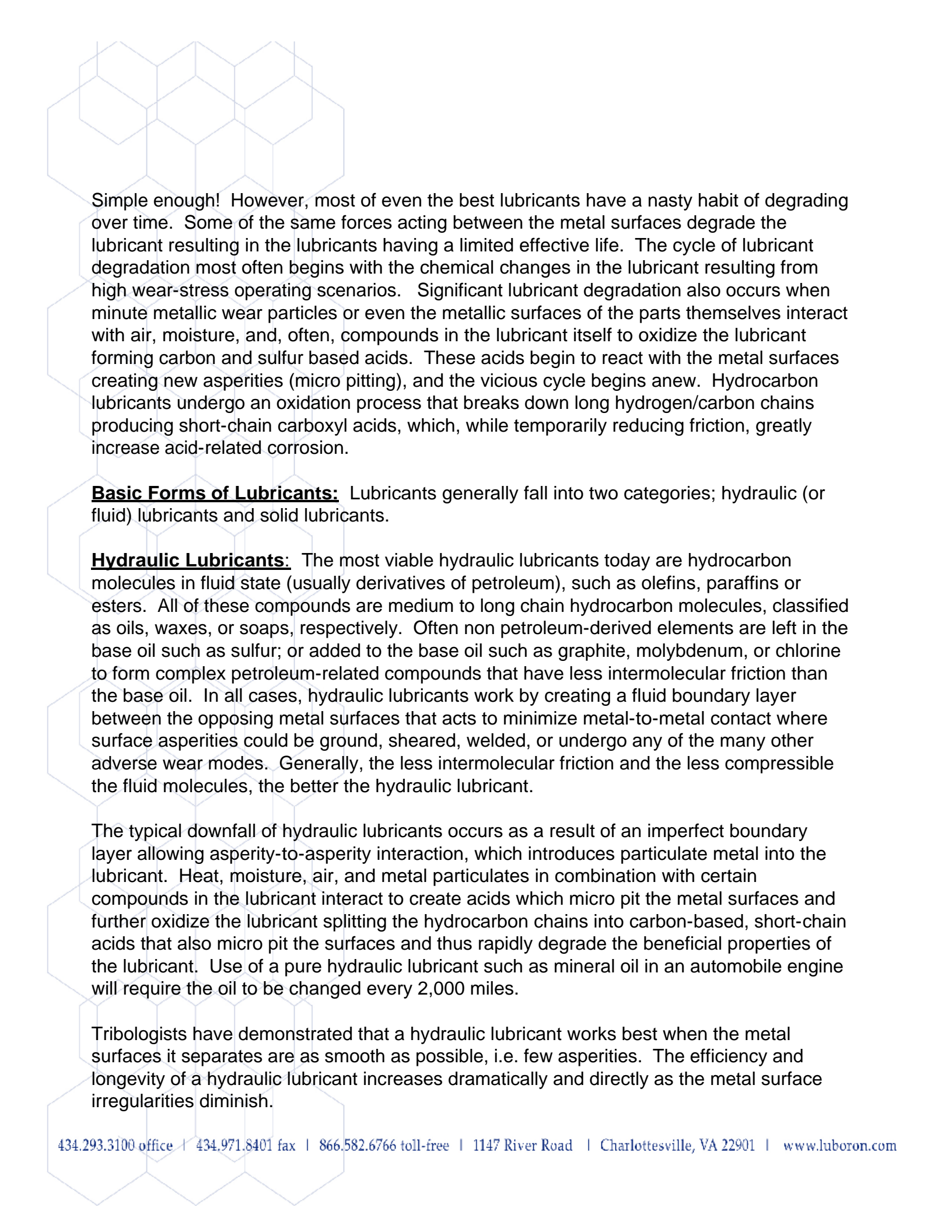


## The Evolution and Benefits of a High-Performance Biodegradable Lubricant

**The Problem:** Tribology, the scientific study of friction, wear, and lubrication, has provided industry with meaningful insights into the varied forces created by and resulting from the interaction of opposing metal surfaces. As the movement and pressure between such surfaces increase, so does friction. Increased friction causes increased heat. Even the most finely polished metal surfaces have irregular surface peaks and valleys or “asperities.” Friction, and heat cause the destruction of asperities resulting in metal particulates aggregating between the surfaces. Initially these particulates act as grinding agents that gouge out more particulates. These metallic particulates react with moisture, impurities and lubricant additives to create corrosive acids that further pit the surfaces creating more asperities and oxidizing lubricant oils to create additional acidic compounds. These acids accelerate the wear related to acidic micro pitting. With sufficient heat (caused by pressure and friction), an oxidized lubricant rapidly deteriorates, the particulates melt and the surfaces essentially weld together resulting in the working failure of the metal parts.

**The Challenge of a Lubricant:** Given the "Problem," a lubricant is, by definition, anything, which prevents or delays the onset of parts failures. So, what can a lubricant do to abate this process? To delay wear related parts failure, a lubricant must reduce metal-to-metal contact and thereby reduce particulate wear from the interaction of opposing asperities. The lubricant must also reduce acid related corrosive micro pitting which produces new asperities.

The method of reducing metal-to-metal asperity interaction generally must be one that does not increase and preferably decreases the friction and related heat generated by the moving opposing surfaces. Therefore, a good lubrication regimen reduces the particulate metals produced by surface-to-surface contact (generally referred to as “wear”) and reduces the friction-related heat of the operating surfaces. Just as importantly, the lubricant or the byproducts of either the lubricant, or the chemical additives in the lubricant, must not create corrosive compounds. In practice, these desired lubricant properties are synergistic and the result is generally longer-lived parts operating with less energy input required to produce a given workload.



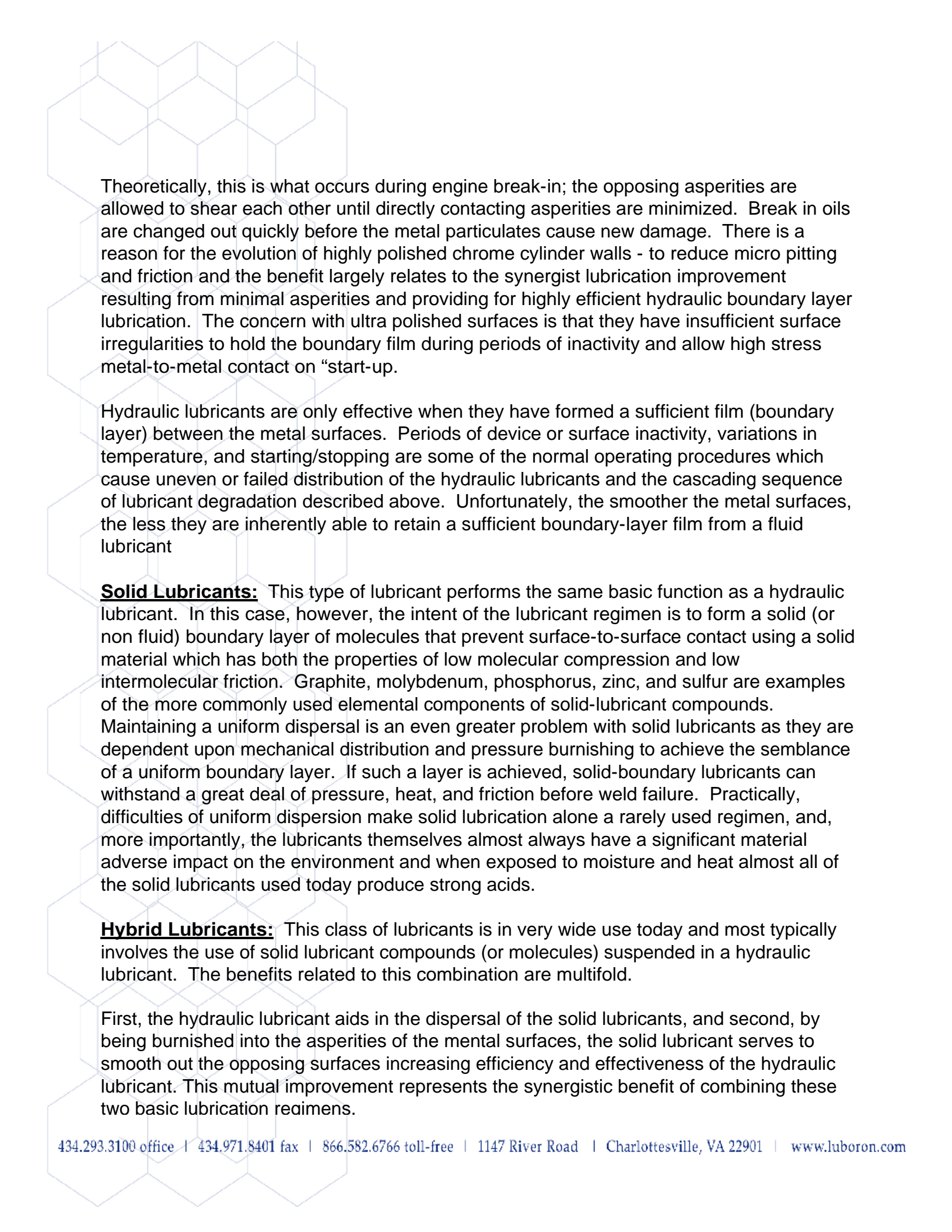
Simple enough! However, most of even the best lubricants have a nasty habit of degrading over time. Some of the same forces acting between the metal surfaces degrade the lubricant resulting in the lubricants having a limited effective life. The cycle of lubricant degradation most often begins with the chemical changes in the lubricant resulting from high wear-stress operating scenarios. Significant lubricant degradation also occurs when minute metallic wear particles or even the metallic surfaces of the parts themselves interact with air, moisture, and, often, compounds in the lubricant itself to oxidize the lubricant forming carbon and sulfur based acids. These acids begin to react with the metal surfaces creating new asperities (micro pitting), and the vicious cycle begins anew. Hydrocarbon lubricants undergo an oxidation process that breaks down long hydrogen/carbon chains producing short-chain carboxyl acids, which, while temporarily reducing friction, greatly increase acid-related corrosion.

**Basic Forms of Lubricants:** Lubricants generally fall into two categories; hydraulic (or fluid) lubricants and solid lubricants.

**Hydraulic Lubricants:** The most viable hydraulic lubricants today are hydrocarbon molecules in fluid state (usually derivatives of petroleum), such as olefins, paraffins or esters. All of these compounds are medium to long chain hydrocarbon molecules, classified as oils, waxes, or soaps, respectively. Often non petroleum-derived elements are left in the base oil such as sulfur; or added to the base oil such as graphite, molybdenum, or chlorine to form complex petroleum-related compounds that have less intermolecular friction than the base oil. In all cases, hydraulic lubricants work by creating a fluid boundary layer between the opposing metal surfaces that acts to minimize metal-to-metal contact where surface asperities could be ground, sheared, welded, or undergo any of the many other adverse wear modes. Generally, the less intermolecular friction and the less compressible the fluid molecules, the better the hydraulic lubricant.

The typical downfall of hydraulic lubricants occurs as a result of an imperfect boundary layer allowing asperity-to-asperity interaction, which introduces particulate metal into the lubricant. Heat, moisture, air, and metal particulates in combination with certain compounds in the lubricant interact to create acids which micro pit the metal surfaces and further oxidize the lubricant splitting the hydrocarbon chains into carbon-based, short-chain acids that also micro pit the surfaces and thus rapidly degrade the beneficial properties of the lubricant. Use of a pure hydraulic lubricant such as mineral oil in an automobile engine will require the oil to be changed every 2,000 miles.

Tribologists have demonstrated that a hydraulic lubricant works best when the metal surfaces it separates are as smooth as possible, i.e. few asperities. The efficiency and longevity of a hydraulic lubricant increases dramatically and directly as the metal surface irregularities diminish.



Theoretically, this is what occurs during engine break-in; the opposing asperities are allowed to shear each other until directly contacting asperities are minimized. Break in oils are changed out quickly before the metal particulates cause new damage. There is a reason for the evolution of highly polished chrome cylinder walls - to reduce micro pitting and friction and the benefit largely relates to the synergist lubrication improvement resulting from minimal asperities and providing for highly efficient hydraulic boundary layer lubrication. The concern with ultra polished surfaces is that they have insufficient surface irregularities to hold the boundary film during periods of inactivity and allow high stress metal-to-metal contact on “start-up.

Hydraulic lubricants are only effective when they have formed a sufficient film (boundary layer) between the metal surfaces. Periods of device or surface inactivity, variations in temperature, and starting/stopping are some of the normal operating procedures which cause uneven or failed distribution of the hydraulic lubricants and the cascading sequence of lubricant degradation described above. Unfortunately, the smoother the metal surfaces, the less they are inherently able to retain a sufficient boundary-layer film from a fluid lubricant

**Solid Lubricants:** This type of lubricant performs the same basic function as a hydraulic lubricant. In this case, however, the intent of the lubricant regimen is to form a solid (or non fluid) boundary layer of molecules that prevent surface-to-surface contact using a solid material which has both the properties of low molecular compression and low intermolecular friction. Graphite, molybdenum, phosphorus, zinc, and sulfur are examples of the more commonly used elemental components of solid-lubricant compounds. Maintaining a uniform dispersal is an even greater problem with solid lubricants as they are dependent upon mechanical distribution and pressure burnishing to achieve the semblance of a uniform boundary layer. If such a layer is achieved, solid-boundary lubricants can withstand a great deal of pressure, heat, and friction before weld failure. Practically, difficulties of uniform dispersion make solid lubrication alone a rarely used regimen, and, more importantly, the lubricants themselves almost always have a significant material adverse impact on the environment and when exposed to moisture and heat almost all of the solid lubricants used today produce strong acids.

**Hybrid Lubricants:** This class of lubricants is in very wide use today and most typically involves the use of solid lubricant compounds (or molecules) suspended in a hydraulic lubricant. The benefits related to this combination are multifold.

First, the hydraulic lubricant aids in the dispersal of the solid lubricants, and second, by being burnished into the asperities of the metal surfaces, the solid lubricant serves to smooth out the opposing surfaces increasing efficiency and effectiveness of the hydraulic lubricant. This mutual improvement represents the synergistic benefit of combining these two basic lubrication regimens.

Solid components can be increased in proportion to the hydraulic lubricant to help handle higher pressures and temperatures. Hybrid lubricants allow today's gasoline automobile engines to safely go an average of 5,000 miles between oil changes. Where hybrid lubricants are not recommended is in the "break in" period. This is because the solids together with the metal particulates from sheared asperities tend to collect and varnish or bake themselves into the spaces between the remaining asperities where their chemical interaction produces strong micro pitting acids. Moreover, the buildup of these acidic gums prevents retention of the oil film necessary to maintain the fluid boundary layer

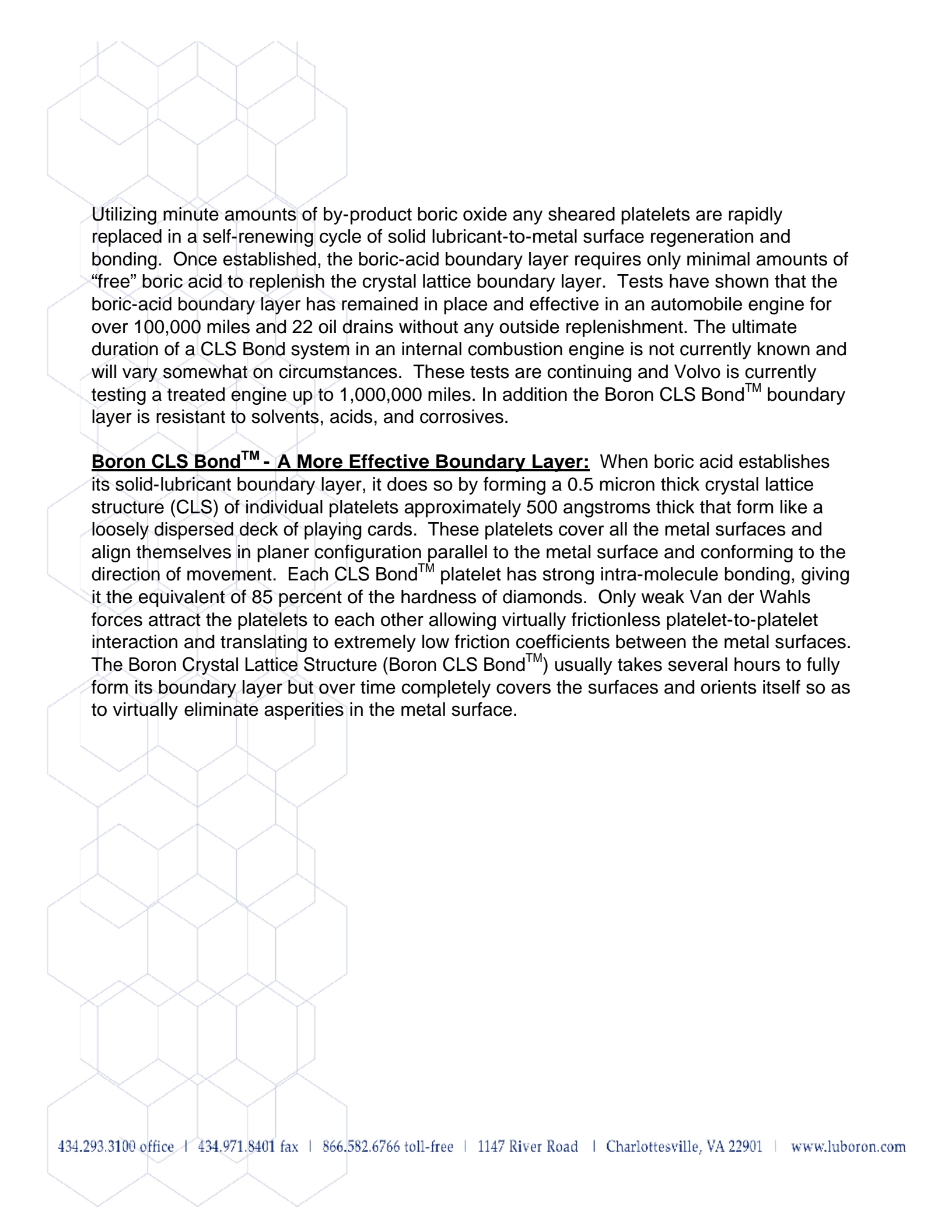
The most significant downside of today's advanced hybrid lubricants continues to be that the solids are a significant environmental concern and most are soon to be eliminated due to the implementation of more stringent government regulations. Actual operating constraints reflect the individual limitations of each regimen. Solids are not permanent, requiring replenishment with each oil change; they are dependent upon the hydraulic lubricant (carrier) for dispersal and are therefore subject to the limitations of hydraulic dispersal.

Moreover, the converse to the mechanical synergy is the chemical dysfunction wherein most solid lubricants interact with metallic particulate catalysts to accelerate the acidification of the hydraulic lubricant. Concurrently, wear metal particles and the metal surfaces themselves oxidize the hydraulic lubricants' long hydrocarbon chains leading to breakdown of the hydraulic lubricant into carbon-based acids, thus further contributing to the corrosion and micro pitting of the metal surfaces. The result: in the short term there is less oil use and less initial wear, but over time the contaminates ultimately oxidize the fluid lubricant greatly reducing its boundary-layer effectiveness and greatly increasing the fluid lubricant's acidic corrosion potential.

## **Permanent, Effective, Synergistic and Biodegradable** **Boron CLS Bond™**

In 1995, Dr. Ali Erdemir patented boric acid as a solid boundary-layer component additive to hydraulic lubricants. Dr. Erdemir's patents were the result of years of research at Argonne National Laboratory.

**Boron CLS Bond™ - A Permanent Solid Boundary Layer:** Boric acid goes through a complex interaction with virtually all metal surfaces where it creates macro molecular and covalent bonds with the metal surface to form a highly adherent crystal lattice of boric acid platelets



Utilizing minute amounts of by-product boric oxide any sheared platelets are rapidly replaced in a self-renewing cycle of solid lubricant-to-metal surface regeneration and bonding. Once established, the boric-acid boundary layer requires only minimal amounts of “free” boric acid to replenish the crystal lattice boundary layer. Tests have shown that the boric-acid boundary layer has remained in place and effective in an automobile engine for over 100,000 miles and 22 oil drains without any outside replenishment. The ultimate duration of a CLS Bond system in an internal combustion engine is not currently known and will vary somewhat on circumstances. These tests are continuing and Volvo is currently testing a treated engine up to 1,000,000 miles. In addition the Boron CLS Bond™ boundary layer is resistant to solvents, acids, and corrosives.

**Boron CLS Bond™ - A More Effective Boundary Layer:** When boric acid establishes its solid-lubricant boundary layer, it does so by forming a 0.5 micron thick crystal lattice structure (CLS) of individual platelets approximately 500 angstroms thick that form like a loosely dispersed deck of playing cards. These platelets cover all the metal surfaces and align themselves in planer configuration parallel to the metal surface and conforming to the direction of movement. Each CLS Bond™ platelet has strong intra-molecule bonding, giving it the equivalent of 85 percent of the hardness of diamonds. Only weak Van der Waals forces attract the platelets to each other allowing virtually frictionless platelet-to-platelet interaction and translating to extremely low friction coefficients between the metal surfaces. The Boron Crystal Lattice Structure (Boron CLS Bond™) usually takes several hours to fully form its boundary layer but over time completely covers the surfaces and orients itself so as to virtually eliminate asperities in the metal surface.