

Development and Implementation of Lubricants for Stationary Gas Engines Powered by Biogas

Kenneth M. Tyger, OMA I
Oil Monitoring Analyst
Technical Services
American Refining Group, Inc
77 North Kendall Avenue
Bradford, Pennsylvania 16701

ABSTRACT

The objective of this work is to describe the systematic approach and processes behind the American Refining Group, Inc. development, testing, and implementation of biogas engine oils for locations (farms) incorporating anaerobic digestion technology for on-site cogeneration of heat and power. The aforementioned biogas oils, known as **Brad Penn**[®] Biogas Engine Oils, were formulated and tailored specifically to service stationary internal combustion engines modified to run where influent gas (methane) is generated from anaerobic digestion of animal manure, compost and/or landfill residue. The gas produced via this process contains high concentrations of hydrogen sulfide (H₂S) and other contaminants inherently corrosive to engine components. Essentially, an engine oil was needed with specific chemistry/characteristics like “reserve alkalinity” to neutralize the acid produced and to protect internal engine components from damage.

INTRODUCTION

According to the AgSTAR Program (a voluntary effort jointly sponsored by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture, and the U.S. Department of Energy) as of April 2010, there are an estimated 151 anaerobic digester systems operating at commercial livestock farms (dairy, swine, poultry and beef) throughout the United States (31 states in total). Our involvement with the development of an effective engine oil lubricant for biogas powered SGE (stationary gas engine) systems materialized out of necessity as word began to reach engine oil manufacturers regarding the growing populace of farms incorporating anaerobic digestion technology. This was being done without an understanding of the actual corrosive nature and volatility of the influent digester gas, which typically contains (Figure 1.) 60% CH₄ (Methane), 40% CO₂ (Carbon Dioxide), and trace amounts of H₂O (Water), H₂S (Hydrogen Sulfide) and NH₃ (Ammonia). Additionally, little guidance was provided or available regarding the selection of an appropriate engine oil lubricant for these systems. Due to anaerobic digestion being a known art, many individuals, specifically farmers, were well versed on the

“ins and outs” of the technology. Likewise, the diversity/availability of SGE’s for this specific service. OEM’s (Original Equipment Manufacturer) of these engines, include Caterpillar[®], Jenbacher[®], Waukesha[®], GM[®], Ford[®] and the Spanish made Guascor[®] engine. Engine lubricant selection was another matter, and farmers utilizing biogas powered engines were essentially left to rely on word of mouth when selecting appropriate type and brand of engine oil. As previously mentioned, engines powered by biogas require an oil with reserve alkalinity to neutralize the acid generated by H₂S during the combustion process.

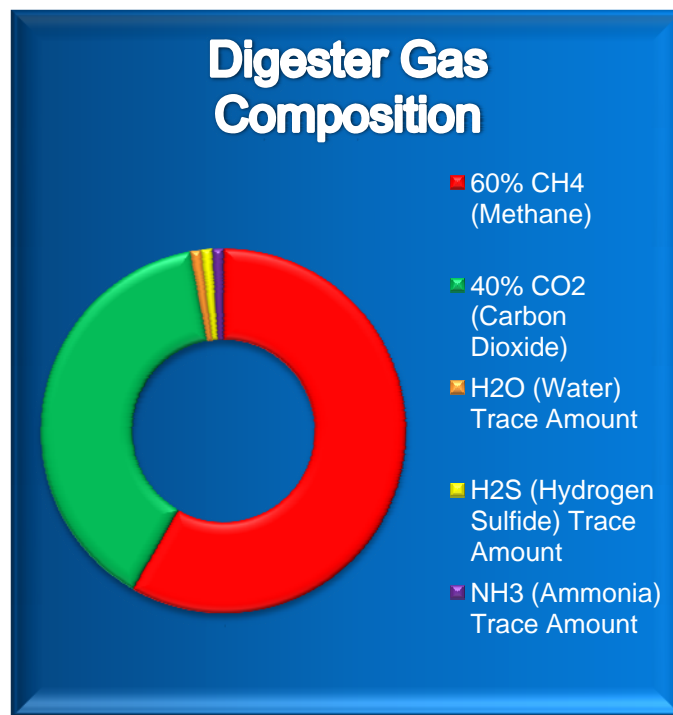


Figure 1. Typical Digester Gas Composition

One particular variety of engine oil various farm maintenance personnel utilized was RRDEO (railroad diesel engine oil), due to its high base chemistry. RRDEO’s BN (Base Number) is typically 13, which is needed to neutralize acids formed during rigorous service. The higher the oil’s BN, the more alkalinity it incorporates, thus increasing the oil’s effectiveness in

controlling corrosive acids formed during the internal combustion process. Due to recent progressive emission and fuel mandates, RRDEO's are now offered with reduced SAPS (sulfated ash, phosphorous and sulfur), translating to a product with lower BN. Later inquiries made to on-site farm engineers and maintenance personnel confirmed that "conventional" stationary gas engine oils designed for use in engines fueled by natural gas or marginally 'sour' landfill gas typically did not possess sufficient reserve alkalinity. Thus, these did not provide the required engine protection or oil drain longevity that was desired in their biogas fueled systems.

The time had come for **Brad Penn**[®] Lubricants to commence development and production of a biogas engine oil that was designed to not only offer high levels of reserve alkalinity to effectively neutralize acidic components generated by combustion of biogas, but also one possessing sufficient levels of detergency to promote the potential for the increased oil drain intervals universally desired.

TRIAL PARTICIPANT

In April 20, 2009, American Refining Group, Inc. representatives visited an anaerobic digester equipped dairy farm known to utilize RRDEO with a total BN of 13. The intent was to perform a trial run of our product, beginning with the transition from the aforementioned engine oil to our newly created/experimental **Brad Penn**[®] High Ash Biogas Engine Oil. This transition (trial) was necessary, as farm personnel had been notified that their current product was being discontinued by the manufacturer and replaced with "modern" RRDEO possessing considerably different chemistry. As mentioned previously, the change was inevitable since locomotive engines, traditionally powered by high sulfur diesel fuel, were now operating on low sulfur fuel, therefore eliminating the necessity for higher BN laden oil. Although the lowered BN is better suited for its intended application (railroad diesel engine), it is not recommended for stationary gas engines running on biogas. Our experimental biogas engine oil was formulated with this philosophy in mind, but with enhanced levels of alkalinity (15 BN) as well as select, proprietary components to exceed the performance of the 13 BN RRDEO. Anything lower than 10 BN and the product characteristics/performance would likely reflect that of the new, unsuitable RRDEO.

The stationary gas engine utilized by the trial participant was a Caterpillar[®] G342, which without the elevated H₂S exposure, would typically require/utilize a low ash SGEO (Stationary Gas Engine Oil) formulation. For reference, stationary gas engine lubricants generally are classified according to their ash level (Table 1.).

The selection of a suitable SGE lubricant for an application depends on the quality/composition of the influent gas burned in the engine. This gas can vary significantly, as natural gas (predominantly methane),

Ash Content (% wt)	Classification
<0.1	Ashless
0.4-0.6	Low Ash
0.7-1.0	Medium Ash
>1.0	High Ash

Table 1. Stationary Gas Engine Oil Ash Content Classifications

sour gas (high sulfur), city gas (high hydrogen), sewage gas (hydrogen sulfide) and landfill gas (corrosive organic halides) are known examples of the different characteristics that require different properties from lubricating oil. Careful selection/development is crucial for optimal operating conditions for these specific applications.

Prior to commencement of our trial, we felt it essential to define a number of specific test criteria:

-How do we effectively construct a suitable trial?

-Why have we chosen this particular test participant?

-What do we need to specifically target during the trial?

The trial began simply enough, as the engine was shut down, the existing oil drained for analysis and all filters changed. The reservoir was replenished with the test lubricant, and the system was re-started. Trial participant/farm maintenance personnel were initially instructed to sample the biogas oil at 50 hour intervals and submit them to a pre-determined independent oil analysis laboratory. The decision of 50 hour sampling increments was made for two reasons:

1. **We did not want to miss identifying any oil deterioration that could be damaging to the engine by arbitrarily extending the sampling intervals.**
2. **Analyzing the oil at pre-determined 50 hour intervals would initially give a meaningful number of data points to establish a trend for several critically important oil performance parameters such as TBN, Viscosity, Acid Number, Oxidation and Nitration.**

At the onset of evaluation we learned the quantity and quality of the gas produced by a digester at any given date/hour can vary significantly and unbeknownst to us; influent gas H₂S streamed to digesters could be treated in a hydrogen sulfide biological "scrubber" system (Figure 2.) before entering the engine. Hydrogen sulfide scrubbers work by cleansing, or greatly reducing, the H₂S from the influent gas flow. After learning that our trial participant incorporated this type of system, our anxieties subsided, since our new biogas oil would not likely be exposed to "anticipated" high levels of H₂S, levels greater than 1,000 ppm (parts per million).



Figure 2. Hydrogen Sulfide (H₂S) Scrubbers

We also learned that the digester methane system at the trial participant's location was installed and implemented in April 2008, a relatively young system in comparison to older, established Pennsylvania farm systems we had become aware of. Although the hydrogen sulfide scrubber was installed on October '08, it was not operational until late November '08. Unfortunately for our intended testing/monitoring, we were alerted to the fact that the H₂S scrubber worked somewhat "intermittently" and because of this did not know exactly what conditions the oil was being subjected to at any given moment. Analyzing the oil at pre-determined 50 hour intervals was expected to help establish a suggested oil drain interval to maximize the useful life while ensuring that the engine continued to receive adequate lubrication and protection against the effects of the 'contaminants' in the digester gas. Comparisons of these sample results would be used against our product's pre-determined oil analysis baselines prior to testing. It was also prudent to examine sample(s) of the "former" 13 BN product, both new and used, to acclimate ourselves with said product's composition and performance characteristics. Prior to the implementation of our product, we were notified that the last (2) performed oil drains had a recorded 290 and 350 service hours respectively, or an average of 320 hours. The trial participant was instructed to continue taking samples at the pre-determined intervals until notified that the interval need adjusted and/or the oil's need to be changed. They were also instructed to continue with the documentation of the hours of use on the oil between samplings and the cumulative engine hours at each sampling point. Additionally, we requested that the H₂S scrubber be tested and the data recorded every two days, with the results faxed or e-mailed to our facility every week for monitoring. As previously indicated, the amount of H₂S and other contaminants in the influent gas have a very significant effect upon the ability of the oil to neutralize any acids generated during combustion. Recognizing the possibility that not every farm incorporating AD technology utilizes a hydrogen sulfide scrubber, it was important to take advantage of this specific learning opportunity and to correlate

scrubber performance and influent gas profile with the oil analyses. This data obviously was valuable to the evaluation of the **Brad Penn**[®] High Ash Biogas Engine Oil and the trial participant's SGE (Figure 3.).



Figure 3. Caterpillar[®] SGE setup in operation

DATA INTERPRETATION

After two drain cycles utilizing the **Brad Penn**[®] High Ash Biogas Engine Oil in the trial participant's engine, we were able to observe a 39% (Table 3.) and 59% (Table 4.) drain interval improvement respectively over the previously established average drain interval of 320 hrs. In addition, compilation and review of all test data indicated that our **Brad Penn**[®] High Ash Biogas Engine Oil had performed admirably in what we deemed to be major areas of focus/concern. Wear metals (copper, iron, chromium, aluminum, lead) remained at nominal concentrations and remained consistent throughout testing as time increments increased. We considered this excellent data; as our oil proved formidable against the corrosiveness of the influent gas. Viscosity (measurement of a lubricant's resistance to flow, or thickness of lubricant) remained an SAE 40 grade (12.5 – 16.3 Viscosity @ 100°C) well into the 300 hr mark, increasing slightly into but never exceeding the limits of an SAE 50 as testing hours increased. Again, we considered this excellent information, considering the severe operating conditions, influent gas contaminants, and the increasing hrs of service to which the oil was being subjected. Acid Numbers (AN-measures acidic material in lubricants) and Base Numbers (BN-measures the alkaline reserve of the lubricant/ability to neutralize acid) were closely evaluated on each sample analysis, and as hours increased, the **Brad Penn**[®] High Ash Biogas Engine Oil maintained a sufficient amount of "reserve alkalinity." Oxidation/Nitration (chemical processes that could lead to increased viscosity and deposit formation) parameters remained low and consistent throughout testing. These results, along with the established baselines, provided condemning limits that were used against all recorded data. After all parameters were taken into consideration, the

Reference A - 446 Hrs

- Nitration Condemning limit: Marginal 8 - Caution 17
- Oxidation Cond. Limit: Marginal 12 - Caution 28
- AN Condemning Limit: Marginal 3.9 - Caution 7
- BN Condemning Limit: Marginal 7 - Caution 4
- Viscosity (HIGH) Cond. Limit: Marginal 16.4 - Caution 22

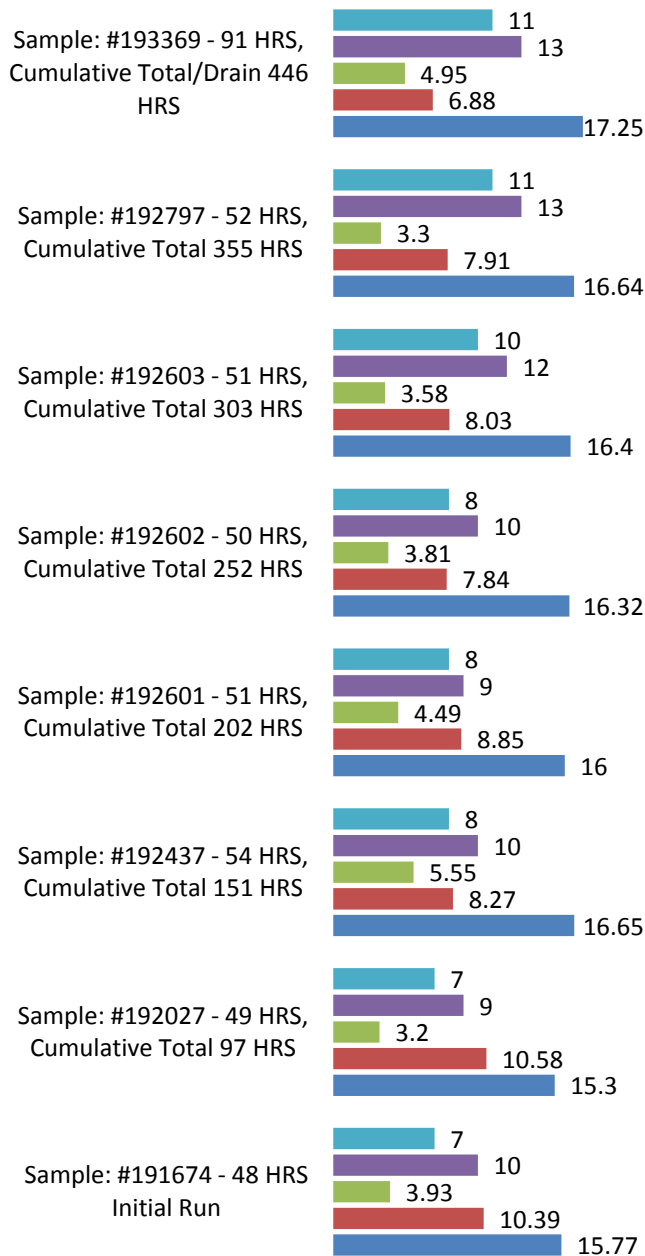


Table 3. Reference A / Test Data from G342 Stationary Gas Engine

Reference B - 509 Hrs

- Nitration Condemning Limit: Marginal 8 - Caution 17
- Oxidation Cont. limit: Marginal 12 - Caution 28
- AN Condemning Limit: Marginal 3.9 - Caution 7
- BN Condemning limit: Marginal 7 - Caution 4
- Viscosity (HIGH) Cond. Limit: Marginal 16.4 - Caution 22

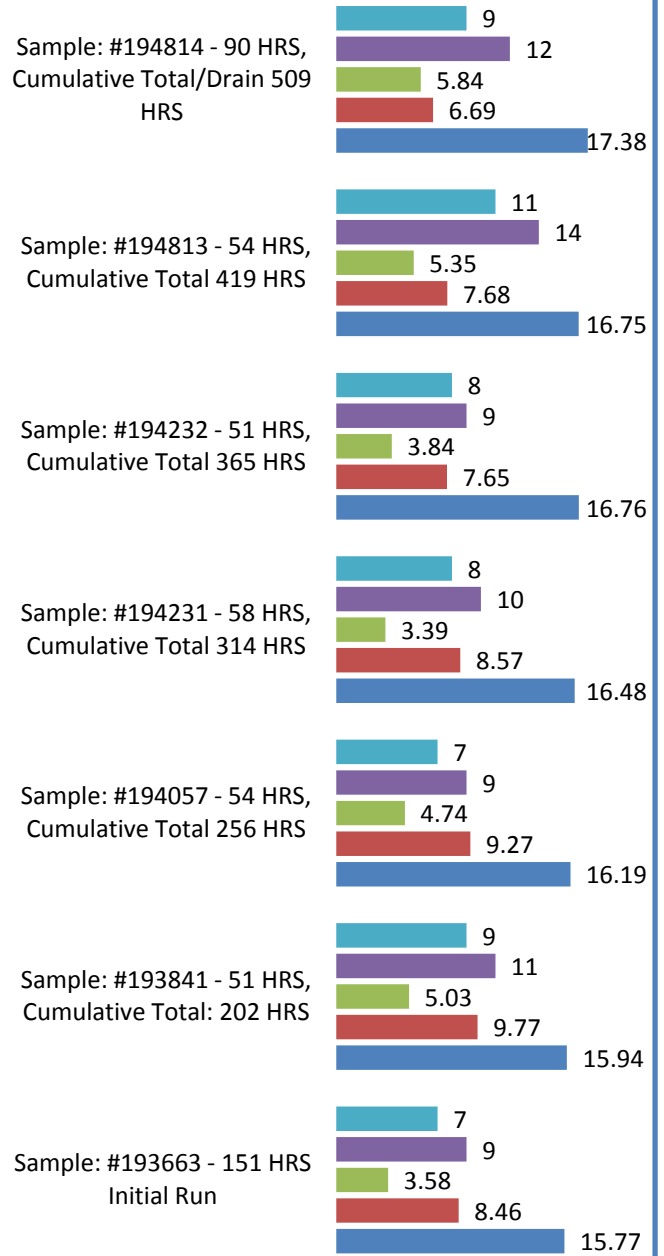


Table 4. Reference B / Test Data from G342 Stationary Gas Engine

conservative decision was made to “encourage” the extension of service and to establish a logical end point of safe service life, under the continuation of close monitoring.

THE JOURNEY CONTINUES

With an acceptable foundation based on the data from the initial trial, it was sensible (and practical) to approach future testing/implementation in the same manner. In the months that followed we did precisely that. There have been numerous examples that have made our journey an interesting one. One such example worth noting is our introduction to a farm **NOT** incorporating any type of hydrogen sulfide scrubber system, certainly a condition considered by many to be very important to constructive testing of our product. Although the data obtained from the initial trial participant provided good information on intermittent hydrogen scrubber operation, most farms either have a functioning scrubber or none at all. Although it generated interesting information, the erratic operation of the scrubber system “skewed” the results due to drastically varying concentrations of H₂S and other contaminants in the influent gas. Without a scrubber, a ‘worst case’ scenario was examined where the engine oil was continuously subjected to elevated levels of H₂S. We compensated for this by having H₂S levels monitored on a regularly scheduled basis, which provided a good profile of BN depletion, AN increase and viscosity increase, allowing us to directly correlate the amount of H₂S with the neutralization of the acid generated.

Another interesting example is with our introduction to the Spanish made Guascor® SGE (Figure 4.), which called for the utilization of “medium ash” stationary gas engine oil with a BN of 9 – 11.



Figure 4. Guascor® Stationary Gas Engine in operation

This “new breed” of stationary gas engine appears to be a steadily growing entity, and from our own growing experience, widely used and recommended in new biogas/anaerobic digester applications. Since learning of the Guascor® existence, we have had a steady supply of inquiries from farms that have selected said engines for

combustion of biogas from anaerobic digesters, one in particular being a current **Brad Penn**® customer successfully using **Brad Penn**® High Ash Biogas Engine Oil in an “additional” on-site SGE (Caterpillar®) with two different style engines on location. Because of their satisfaction with the **Brad Penn**® High Ash Biogas Engine Oil product, the customer had asked if it were possible to utilize it in the Guascor® engine, and if so, could the same level of satisfaction/engine performance be expected? The answer was an emphatic “no”, since our research revealed that Guascor® engines specify the use of a medium ash’ (0.7-1.0% wt) product with a 9-11 BN. The Guascor® engine, based on its unique needs, characteristics and attributes, lead to the successful development, testing and implementation of the **Brad Penn**® Medium Ash Biogas Engine Oil (8.9 BN). The following (Table 5.) identifies the various types of stationary gas engines currently running the **Brad Penn**® High Ash and Medium Ash Biogas Engine Oils:

(3) Caterpillar® G342 Engines <i>High Ash</i>	(1) Caterpillar® 3306 Engine <i>High Ash</i>
(3) Caterpillar® 379 Engines <i>High Ash</i>	(2) Guascor® Engine <i>Medium Ash</i>

Table 5. Make/Model of Biogas fed SGE’s utilizing **Brad Penn**® Biogas Oils

As previously mentioned, Jenbacher®, Waukesha®, GM®, Ford® are also recognized for their service in digester systems, although ARG has yet to come across any of these specific engines in operation at anaerobic digester farms.

One last example/situation presented itself when an analysis report of our **Brad Penn**® High Ash Biogas Engine Oil had indicated a rapid depletion of BN, from 15 to 3.35 in just over 200 hrs of service, or 8 1/2 days. This rapid depletion was very puzzling, since the reported results actually contradicted parameters that had been mostly corroborative with previous reports from other farms, particularly with BN and hrs of service. After consulting with the farm engineer responsible for the engine, it was learned that this particular farm utilizes a rich sulfur fertilizer on their surrounding acreage. This new information created concern, since it was obvious that our oil was being asked to combat high H₂S levels on two fronts. Other areas of discussion included the digester system itself, influent gas composition, the possibility of H₂S scrubber installation and engine lubricants previously used. American Refining Group, Inc. personnel visiting the farm were allowed access to the engine room where they were able to extract

samples of influent gas using the Draeger gas detection apparatus. As anticipated, H₂S concentrations exceeded >3000 ppm (parts per million), certainly high levels when comparing to other farms/systems we had gained knowledge from. The SGE₀ product being utilized prior to our oil had a starting BN of 8.6, indicating the alkalinity all but depleted by the 200 hr mark. Once this BN was depleted in the product, it lost its ability to neutralize acidic by-products; by-products that will quickly attack softer internal metals such as Iron, Lead and Copper. Elevated Copper, Lead, AN and severely depleted BN, reported on the 8.6 TBN product analysis, are typically precursors of pending bearing and/or other mechanical failure. Regardless of brand, oil cannot replace what was lost via wear and cannot rectify the damage already done. After just (3) drain cycles utilizing our **Brad Penn**[®] High Ash Biogas Engine Oil, lowered levels of copper and iron (wear) metals were reported and we were collectively pleased with the wear metal trend pattern. Again, oil cannot replace what was lost (metal) via wear and cannot rectify the damage already done BUT the right oil can certainly help prevent wear, especially in this application. We were witness to this positive attribute through analysis. With 209, 310 and 210 hrs of **Brad Penn**[®] High Ash Biogas Engine Oil service time analyzed, we made the suggestion to drain the oil at 200 hr increments and send used oil samples for “turn-around” analysis. The game plan was to be able to advise as to what we thought to be a comfortable limit (cap) for drain interval. Knowing that our oil can be run at 310 hrs and still have reserve alkalinity available (while exposed to such high levels of H₂S) is encouraging, but our goal was to find that “happy medium” where this specific customer felt comfortable with both the longevity and performance of our oil.

CONCLUSION

Beginning in March of 2009, we commenced with what eventually led to a series of successful field tests with our **Brad Penn**[®] Biogas Engine Oils in engines fueled with biogas generated from anaerobic digestion of (predominantly) bovine manure. The majority of the aforementioned were conducted in Caterpillar[®] SGE's in conjunction with closely monitored oil testing. In most instances, increased drain intervals have been accomplished and in all instances, excellent engine protection was provided as evidenced by engine wear metal profiles that remained consistently low and virtually unchanged throughout the entire testing period. Backed by the impressive analytical data from our field tests, product accessibility and painstaking dedication to working closely with our customers, the **Brad Penn**[®] Biogas Engine Oils have earned the reputation of being “the oil” to run in biogas powered engines, mainly due to their potential to increase drain intervals and their proven engine protection/performance over competitive products being used as engine lubricant. The ‘caveat’ is, and always will be, the need to closely and carefully monitor the oil while in use/application in order to establish satisfactory drain intervals while assuring that the engine is being properly protected. This evaluation

involves carefully selected oil sampling intervals; prompt testing of the used oil at each interval to insure that the oil is not beyond its useful life, establishing trend for “critical” performance parameters such as BN, Viscosity, AN, Oxidation/Nitration and individual(s) to properly interpret and explain oil analyses. Selling these products (in our opinion) means providing a significant level of service and expertise to make certain that the products perform as advertised. The **Brad Penn**[®] Biogas Engine Oils ARE NOT products that a manufacturer/distributor can simply supply to the end user/customer and walk away! In just over a year's time, the American Refining Group, Inc. Technical Services department has been meticulously monitoring our biogas oils and SGE performance at (9) farms, with (8) of those being current AgStar Program recognized AD farm sites. We are also continuing work with our selected independent oil analysis laboratory, so that when oil is utilized in applications the end user can send oil samples and have reported operating conditions and other situations correctly interpreted. In addition, American Refining Group, Inc. Technical Services Dept. is available for questions, explanations, and/or to resolve any associated issues a customer might have. Again, it was NEVER the intention to “provide and forget” these unique products. Without some type of targeted training, trying to utilize such products and have success doing so would be difficult, not to mention ill-advised.

Our continuing research shows installation/implementation of these anaerobic digester systems expanding rapidly throughout the United States...as well as globally. We have collectively identified the development of lubricant for biogas powered engines as being a unique opportunity for all involved, particularly since it is still, in many facets, within the early stages domestically. Because each situation will be unique in its own right, we have learned that we should not offer general recommendations to fit all cases, nor would we want to do so. Our **Brad Penn**[®] Biogas Engine Oils were designed, formulated and tailored with specific service in mind. In addition, although we have found a number of similarities within the anaerobic digestion systems we have worked with, it should be noted that there are just as many differences, and we have painstakingly proven our ability to recognize and address each and every deviation accordingly. Individuals feel better knowing that they have our support if/when needed. It has and shall remain a team effort. Should you have any questions regarding this information, please contact the **Brad Penn**[®] Representative responsible for your geographical area or contact the American Refining Group, Inc. Technical Services Department.