COMPANY OVERVIEW

Digital documents and references are made clickable for convenience, where appropriate.

Quick summaries of innovation are available in videos:

TriboTEX elevator pitch (1 min) **Singularity application (3 min)** **Kickstarter video (3 min)**

TriboTEX is introducing a consumer product line with one objective; dramatically reduce friction in both legacy and modern transportation vehicles. We bring a revolutionary approach to lubrication by synthesizing nanomaterials that promote self-organization to form low-friction boundary films when added to existing oils (both base and formulated). The result is a super-slick, silicon-rich, diamond-like carbon (DLC) coating on engine component interfaces and gear surfaces in gearboxes. The lubricious coatings form *in situ* (during operation) from our proprietary, flat, nano-sheets that are synthesized with functionally different sides.

TriboTEX developed synthetic nanotechnologies demonstrating SBIR Phase I feasibility for energy efficiency and longevity in existing machinery and transportation. Developments were guided by extensive bench testing and validated using vehicle tests under real world conditions. After considerable research and optimization, we have increased capacity for nanomaterial production under the SBIR Phase II program. Now we present to you the next big step in lubrication.

DEMONSTRATED PROPERTIES OF TRIBOTEX™ GENERATED COATINGS

- ✓ Formation of complex nanostructure coatings
  - Crystalline nanograins are intermixed with an amorphous matrix
- ✓ Plane alignment of nanocrystalline oxides/carbides correspond to typical "Superlattice" structures
  - Intergranular diffusion of magnesium into iron matrix slows down diffusion of oxygen
- ✓ Top layer consists of silica-doped DLC nanocomposite
  - Defines dynamic superlubricious properties
- ✓ Device level impact on decreasing fuel consumption
  - Up to 10% in larger, older vehicles (ex. 1989 GM K2500 5.7L V8, small block 350)
  - ~5% newer light weight and hybrid vehicles
- ✓ 3-9% improvement documented in vehicle performance case studies by measuring power at the wheels
- ✓ TBO of piston cylinder group projected increase of 4 times

CASE STUDY OVERVIEW

TriboTEX introduced a consumer product line promising to dramatically reduce friction in both legacy and modern transportation vehicles. The revolutionary approach to lubrication is based around proprietary, synthetic nanosheets. The nanomaterials are designed to promote self-organization; **forming low-friction boundary films when added to both base and formulated oils.**

TriboTEX has been synthesizing nano-sheets with functionally different sides (sticky/slick) for **coating metal surfaces inside engines and gearboxes during normal operation**. When added to base oils these nano-sheets travel through the lubricating system with ease and remain relatively inert. However, at interfaces experiencing a normal load these nano-sheets are attached to metal surfaces from the pressure exhibited by the normal load and heat supplied by friction. TriboTEX has developed multiple optimized iterations of these nano-sheets by functionalizing the slick side with catalysts. Catalytic compounds further **improve performance by seeding a lattice structure to promote DLC formation on the very top**. These coatings could provide a novel approach to addressing the issues of friction, engine wear, and fuel consumption. TriboTEX demonstrated the feasibility for energy efficiency and longevity in existing machinery and transportation for the National Science Foundation during the SBIR Phase I.

The ability of TriboTEX nanosheets to generate **films on the surface that retain their lubricating properties even after oil drainage** gives us the confidence to define a **new class of oil additives: surface reconditioners**.

Nanolubrication technology is rather unique in that it creates a self-generating and self-healing boundary film. While the base material itself had not been commonly accepted as solid lubricant it has been widely studied. Specifically, its self-regulating mechanism for low-friction boundary film also compensates for wear (as discussed in the books "Superlubricity" Ch 24 and "Advanced Tribology"[1]). More recently, TriboTEX coatings were featured in a book "Nanovate: Commercializing Disruptive Nanotechnologies"[2].

THE NEED TO IMPROVE EXISTING MACHINERY

Friction is a parasitic force that manifests at contact interfaces in mechanical systems. Many innovative and **promising solutions have been presented over the years but they are rarely cheap**. Diamond-like carbon (DLC) coatings have been slowly making their way from racetracks into production vehicles (at least on some valve stems). Methods for applying plasma sprayed coating pre-production have not yet reached their full potential and do nothing for existing vehicles, equipment, or machinery in use today.

To combat friction in existing cars **the most promising approach is to improve efficiency in vehicles that have already been on the road for years**. This can be achieved without an environmental toll by applying nanomaterials that are already widespread in nature. From a societal perspective, this **technology has the potential to save a large portion of the substantial amount of energy lost to friction** in ubiquitous components such as generators and engines, while simultaneously reducing wear-related material/component failures and associated downtime costs. Numerous industrial and commercial applications will benefit from increased component longevity and more efficient operation of machinery, coupled with labor and energy savings.

In modern automobiles, approximately, one third of the fuel consumed is wasted on internal friction[i]. The energy lost (Table 1) can be attributed to individual subsystems: 11.5% is lost in engine, including a 5% loss in the cylinder/piston group and an additional 5% is loss in the transmission[3].

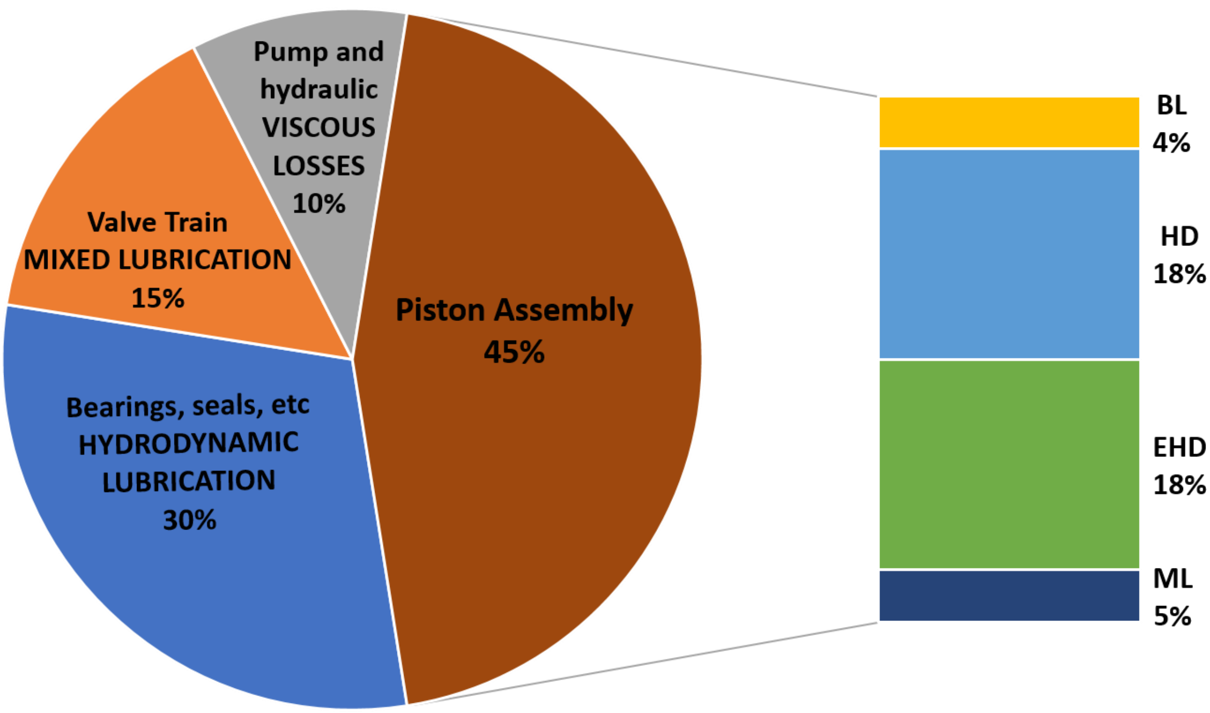


Figure 1. Distribution of frictional losses in internal combustion engines. The 45% of frictional losses of the entire engine occur in the Piston Assembly. The Piston Assembly has many complex interactions the frictional contributions of which are described in further detail in the bar graph on the right. The abbreviations indicate the lubricating regime contributing to frictional losses: **BL**-Boundary Lubrication, **HD**-Hydrodynamic, **EHD**–Elastohydrodynamic, and **ML**–Mixed Lubrication

Older and high mileage cars respond more favorably toward treatment. Newer cars shown less improvements in fuel consumption. Most likely the effect is due to a coating formation of worn parts. Every single vehicle shown improvement in emissions[4]. **There are over 250 million cars in the U.S. with an average age greater than 10 years[3].**

Previous research has predicted that a **successful global application of the proposed technology** in existing transportation systems **will enable an absolute energy savings that exceeds the total energy generated by all currently-deployed photovoltaic, geothermal, and biomass sources combined**.

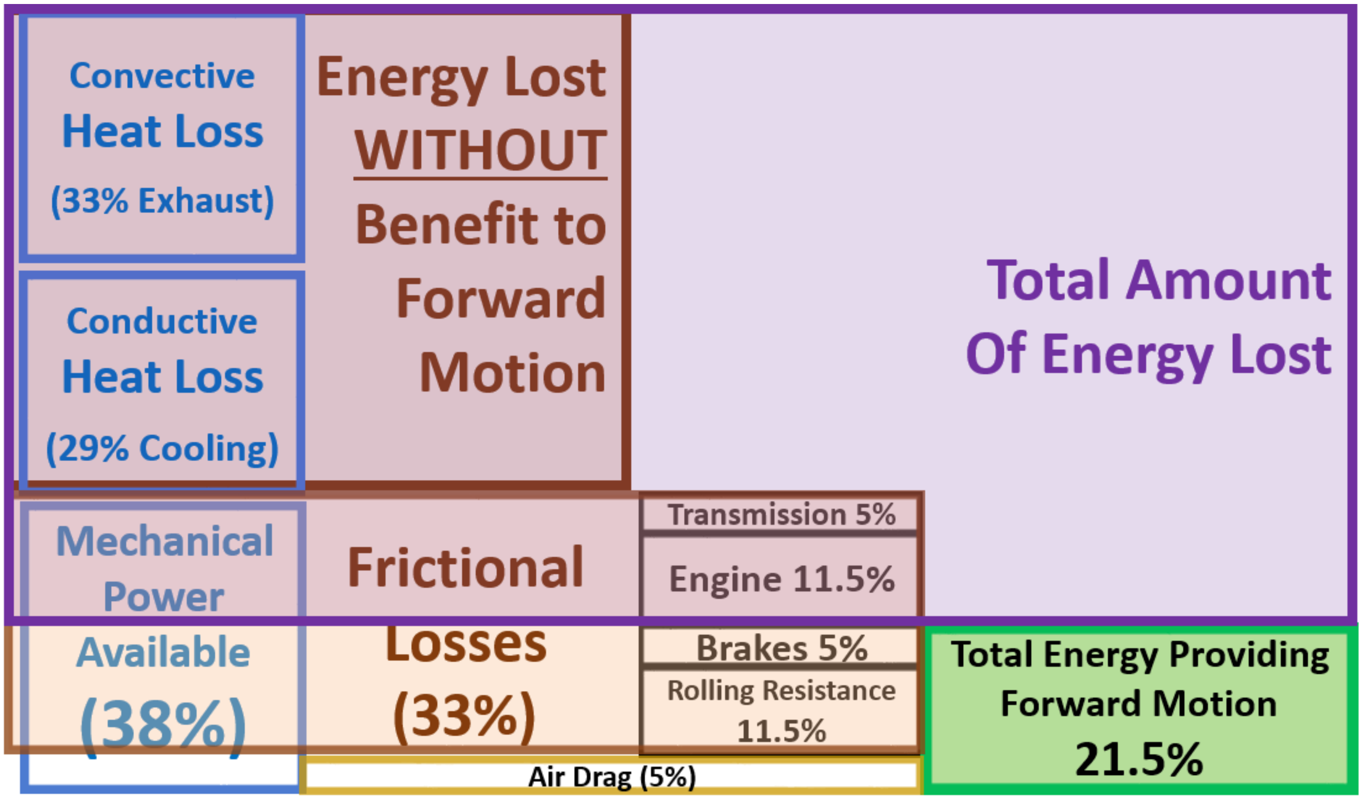


Table 1. Distribution of proportional usage of the energy derived from fuel in internal combustion vehicles[5].

In our previous research, **the film formed has a distinct nanostructure with increased (>20%) microhardness, whereas nanohardness increased by factor of 4 with reduction in elasticity**[1]**.** Such behavior is ideal for wear-reducing, low-friction coatings where the ratio of hardness to elasticity (H/E) plays a defining role. Research done in-house achieved a **friction coefficient that reaches 0.01, which translates to a more than 7-fold reduction in friction losses over well formulated commercial oils.**

The typical formation time for a coating is rather slow, over several hours of continuous friction tests.[1] The **superlubricous properties with a friction coefficient of less than 0.01 are achieved due to mixed lubrication regime intensified by porous structure of the coating**. When the oil is fully drained, the super lubricious properties are retained.[1] These coatings have already been independently tested on a limited set of vehicles in end user automotive applications, and have resulted in a **reduction of fuel consumption by an average of 5%.** Another explanation of such high friction reduction in engine where elasto-hydrodynamic regime dominates is lower thermal conductivity of oxide film compared to metals.

List of Vehicle Case Studies

1) Repairing Effect on Engine with Existing Wear

- ⇒ Compression
- ⇒ Fuel efficiency
- ⇒ Oil Pressure
- ⇒ Tear down inspection

1999 Volkswagen Passat
1.8 AEB Turbocharged
208K miles

2) Dynamometer Measurements of Torque and Power

- ⇒ Torque
- ⇒ Power

2015 Ford Mustang
3.7 L V6 Turbocharged

3) Hybrid Fuel Efficiency

- ⇒ Fuel Efficiency
- ⇒ Head to head road testing

1st Gen Toyota Prius (2000-01)
1.5 L Atkinson Cycle Engine
Toyota Hybrid System

Product Description and Application

TriboTEX manufactured nanomaterials (1g) held in a gel suspension and pre-packaged into 20 mL syringe applicators, branded as CarBOSS coatings, were used to treat the vehicle with higher mileage (204K mi, see Table 1). The application on CarBOSS engine coatings was performed per the instructions on the applicator label:

1. The engine was warmed up to normal operating temperatures (open thermostat) and then shutdown
2. The reddish contents of the 20 mL syringe were emptied into the engine oil fill compartment
3. The vehicle was restarted and allowed to idle for 15 minutes
4. After 500 miles of driving the vehicle was tested to measure the improvements TriboTEX nanomaterial coatings provide.

CASE STUDY: REPAIRING EFFECT ON ENGINE WITH EXISTING WEAR

TriboTEX engine coatings provide many benefits. Nanomaterials deposit on contacting surfaces forming a tribofilm that reduces the parasitic effects of friction. Reduced friction allows more power to become available for moving the vehicle, producing a more efficient utilization of fuel energy. One unique benefit of tribofilm formation is the reversal of existing wear through the deposition of a nanomaterial substrate layer onto which a DLC lattice forms. This mechanism allows for material to be added to worn surfaces during the course operation rejuvenating worn engines to reclaim performance.

TEST VEHICLE

To demonstrate the rejuvenating effects of TriboTEX coatings in an engine with a substantial amount of existing wear, a high-mileage (200K mi) 1999 Volkswagen Passat Wagon was purchased. During the pre-purchase vehicle inspection, low oil pressure (a characteristic symptom of worn engine bearings) was identified confirming the presence of significant wear. Cylinder compression was on the lower end of manufacturer's specifications (see Table 2). The range of variation in measured compression across the cylinders was 15 psi, indicating uneven wear of piston rings commonly observed in higher mileage engines.

Engine	Wheel Base	Trans	Platform	Body Style	Odometer (mi)
1.8 L I4 DOHC turbocharged multi-point injection	**183.8”**	**5-speed Auto**	Fr Engine Fr Wheel Drive	**5-dr Wagon**	**200,912** (test Start)

Table 2. Volkswagen Passat vehicle parameters.

DATA COLLECTION

Data were collected for 32 round trips before nanoparticles treatment and 18 after the introduction of nanoparticles to the engine lubricant. Fuel economy was calculated using the on-board vehicle computer. Specifically, OBDII data from the Mass Air Flow (MAF) sensor was integrated to calculate fuel consumption. Oil pressure was measured before and after each round trip. Oil pressure measurements were taken at the normal operating temperature in two different operating regimes: at idle and at 2000 rpm. Compression testing was performed in accordance with VAG procedures outlined in the Passat manual. Briefly, the procedures called for measurements to be made with: warm engine oil, a fully depressed throttle, a fully charged battery, using 8 second starter crank intervals. After the completion of the testing interval the engine was disassembled by a local mechanic to inspect engine components for tribofilm formation (Figure 3).

TEST ROUTE

The 16-mile (25.8 km) test route was chosen based on the driver's daily commute between Colfax, WA (alt 1972ft/601m) and Pullman, WA (alt 2552ft/778m). All accelerations were made at wide open throttle, to maintain consistency, until highway speeds were reached. For the highway portion of the test route (11mi/17.7k), if doing so did not compromise safety, the driver maintained a consistent cruising speed of 62 mph. Vehicle load configuration and internal weight distribution was maintained through the entire period of data collection.

RESULTS

Parameters measured to assess the ability of TriboTEX coatings to a worn engine demonstrate considerable improvements (See Table 3). Cylinder compression improvements ranged from 9-16%, with the worst cylinders exhibiting the largest improvements. The **total variation between cylinder compression values also decreased by a third** from 15 psi to 5 psi. Improvements in oil pressure were measured for both engine operating regimes, at idle and 2000 rpm.

Figure 2. VW Passat case study test route Pullman/Colfax.

Modest improvements in fuel efficiency were also demonstrated, averaging about 6.25% fuel savings. These fuel savings may seem unimpressive, at 1.5 mpg. However, in the Passat **that comes out to be about 25 extra miles per tank.** If an average consumer goes through one tank of fuel a week, **in one year the savings amount to almost 1300 extra miles without spending an extra dime.** In the Passat where an average fuel tank after the TriboTEX treatment averages out to approximately 400 miles; **these savings amount to 3 free fuel tanks per year.**

There is an interesting nuance in the data, fuel savings are trip dependent. This clearly demonstrates that the TriboTEX coating works by decreasing internal engine friction. For the trips from a higher elevation to a lower elevation (Pullman to Colfax) engine friction makes up a larger portion of the total energy of the consumed fuel. In the scenario where the load the engine experiences increases (lower elevation to higher elevation, Colfax to Pullman) the engine friction is a smaller portion of the total energy provided by the fuel (see Table 1).

1.8L DOHC Turbocharged 20 Valve	Compression by cylinder [psi]				Oil pressure [psi]		Gas mileage [mpg]	
	cyl#1	cyl#2	cyl#3	cyl#4	Idle	2000 rpm	Col->Pul	Pul->Col
Specification	New:145-188psi, wear 101 div 43				>15	>30	city18/22/hwy28	
Before	155	160	165	170	13.1±0.8	34.6±7.3	22.2±0.9	23.9±1.5
After	180	180	185	185	15.8±0.9	38.0±2.4	23.5±1.0	25.6±2.1
Change, %	**+16%**	**+12%**	**+12%**	**+9%**	**+20.4%**	**+9.6%**	**+5.7%**	**+6.8%**

Table 3. VW Passat measured performance parameters. Bottom row indicates percent change to quantify the extent to which the worn engine improved after the TriboTEX coating formed on contacting surfaces.

Visual Inspection of Internal Components

The engine compartment was opened for visual inspection by a local mechanic (Figure 3). The valve cover was removed to gain access to the upper part of the engine for inspecting the coating development on the cam lobes. The oil pan was removed to inspect the parts in the lower end of the engine for wear. Through the opening created by removing the oil pan it was possible to access some of the cranckshaft journal bearings, which were removed for inspection. The tribofilm was visually identified on the crankshaft, bearings surfaces and cam lobes.

Figure 3. Selected pictures from the report provided by a mechanic. With 210K miles on the engine, MHS powder was added at 208K miles. Results were achieved in about 40 motor hours. He extracted hydraulic lifters and main journal bearings for further analysis. Our mechanic described formed film as “polish” and could not hide his admiration of the mirror smooth surfaces.

CASE STUDY: THIRD-PARTY MEASUREMENTS OF TORQUE AND POWER

To examine the effects of TriboTEX engine coatings on engine performance characteristics we employed a third-party performance shop to measure torque and power at the wheels using a full chassis dynamometer. The purpose of the case study was to perform an assessment of TriboTEX engine coatings on vehicle performance in a test vehicle not owned or tested by TriboTEX.

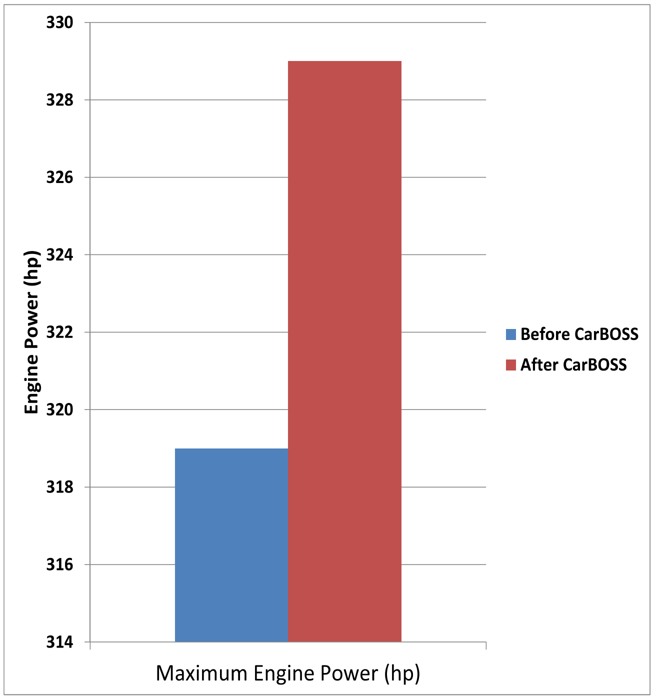
TEST VEHICLES AND DATA COLLECTION

The effects of TriboTEX engine coating on improvements in vehicle torque and power were measured by The Mustang Shop (Kent, Washington) on their in-house full vehicle dynamometer. One of the available shop vehicles (2015 Ford Mustang) was used in the test. To measure changes in torque and power the vehicle was tested on the dynamometer prior to TriboTEX treatment. After recording the baseline metrics, the vehicle was treated with TriboTEX and driven for 500 miles under normal road conditions to ensure full dispersion of nanoparticles and adequate coating formation. After the interval of normal driving the dynamometer test was performed again.

Figure 4. Data collection from a chassis dynamometer at The Mustang Shop (TMS) in Kent, WA. Light blue test vehicle can be in the bottom right of the photo.

RESULTS

The baseline dynamometer measurements recorded the peak engine power at 319 hp and maximum torque at 300 ft-lbs. Average torque was calculated at 284 ft-lbs as a baseline. After being treated with TriboTEX and undergoing 500 miles of driving under normal conditions the dynamometer tests indicated an increase in both power and torque. **Maximum engine power increased by 10 hp**, from 319 hp to 329 hp (+3.1%). **Average torque and peak torque increased** to 311 ft-lbs (+3.7%) and 293 ft-lbs (3.2%), respectfully.



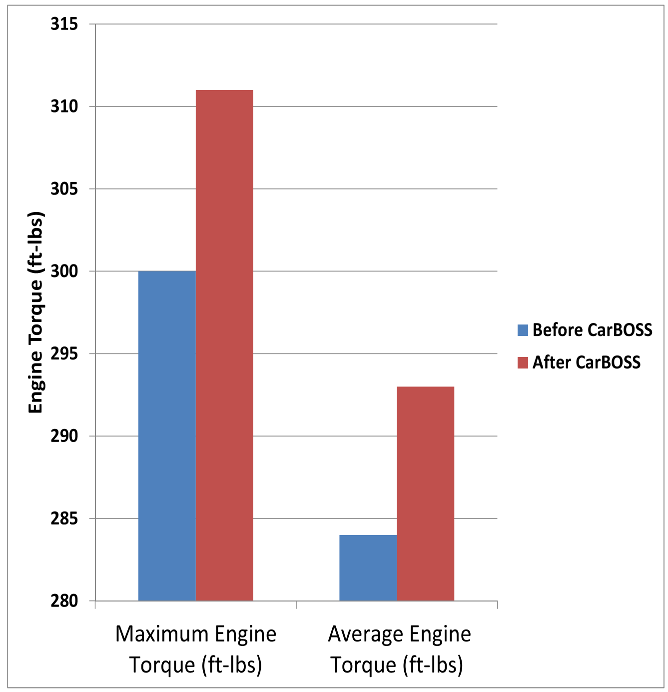


Figure 5. Third party dynamometer performance testing using a custom built 2015 Ford Mustang. Engine power (left) was recorded to increase from 319hp to 329hp. Torque also increased from 300ft-lbs to 311ft-lbs for maximum torque and 284ft-lbs to 293ft-lbs for average torque.

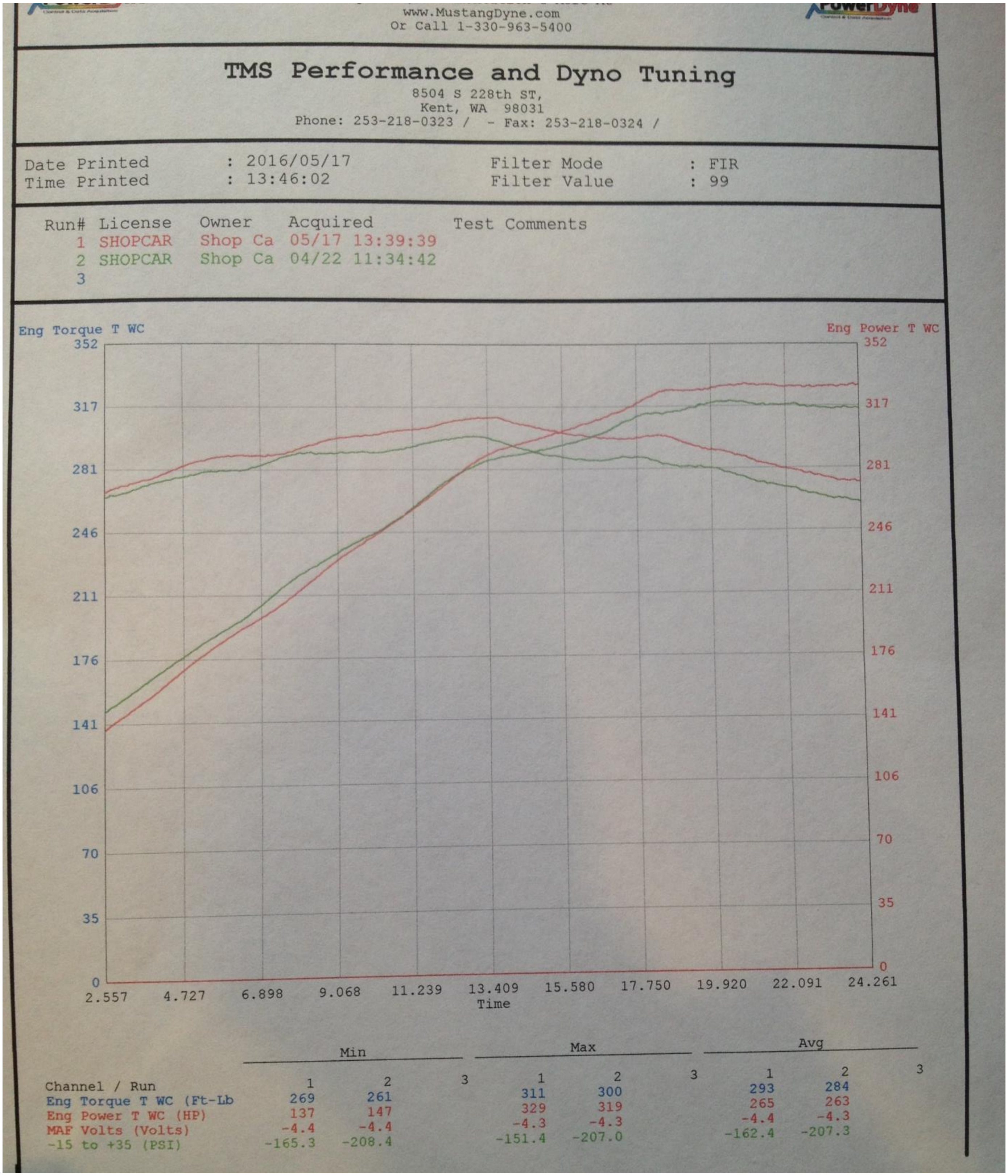


Figure 6. Raw data print out from third party performance testing using a full chassis dynamometer.

CASE STUDY: HYBRID FUEL EFFICIENCY

TriboTEX nanomaterial engine coatings packaged in CarBOSS branded applicators have been added to lubricant systems of multiple consumer vehicles with reports of improved gas mileage, smoother operation and improved performance. Consumer vehicle drivers have reported back to us citing improvements of fuel efficiency that allowed them to gain an extra 30 to 60 miles per tank of fuel, on their daily commutes. Although this consumer feedback is favorable it does not show direct comparison of performance.

The purpose of this case study was to compare two identical vehicles under real world conditions on identical predetermined test routes. To test vehicles in a real-world scenario, two identical make and model, 1st generation Toyota Prius vehicles were driven on the same route. The first route (Route A) was used to collect preliminary data and test the protocol. The second route (Route B) was driven six times, for each vehicle, with three times in one direction and three in the opposite direction, consecutively.

VEHICLES

Figure 7. Two 1st generation Toyota Prius test vehicles: blue baseline vehicle (left), odometer reading 160k miles, and the green vehicle with one application to the engine oil compartment of TriboTEX nanomaterial engine coating (right), odometer reading 203k miles.

Two 1st generation Toyota Prius vehicles (1.5L 4-cylinder Atkinson-cycle Engine with a CVT drivetrain) were used in head-to-head device testing comparisons to measure the effect of TriboTEX engine coatings on hybrid vehicle fuel economy under different road conditions. The differentiating factors between the vehicles were: color, mileage, and an application TriboTEX nanomaterial engine coatings. At the time of testing, the baseline vehicle (blue) and the vehicle with TriboTEX engine coatings (green) had odometer readings of 160k miles and 203k miles, respectively.

Figure 8. Photograph of vehicle odometer readings. The blue baseline Prius is pictured on the left. The green Prius with TriboTEX engine coating is pictured on the right.

Engine	Wheel Base	Transmission	Platform	Body Style	Odometer (mi)	VIN #
1.5 L 1NZ-FXE DOHC I4 VVT-i	**100.4”**	**1-speed planetary gear**	Fr Engine Fr Wheel Drive	**4-dr Sedan**	**203,912**	JT2BK12V310019161 w/ TriboTEX
Electric Motor 273.6 V 33 kW (44 hp) @1040rpm **350 N·m** (258 lb·ft) @0rpm	Weight 2765 lb (1,254 kg)	**THS** Toyota Hybrid System Nihydride Battery	**Toyota MC**		**160,426**	JT2BK12V010035169 Baseline Vehicle

Table 4. Toyota Prius Generation 1 vehicle specifications **Source:** Wikepedia Page

Test Route and Testing Procedures

Two, identical in length, 10-mile test routes with different driving terrains were selected to compare fuel efficiency performance in different scenarios, more representative of real world driving. For all the test routes driven, vehicle cruise speed was maintained at 50-55 miles per hour, depending on safety of the route. The identical routes were between two markers with safe turnaround locations. The first route (Route A, Figure 8) on Almota Road was driven as a preliminary test run to better understand the procedures and ensure safety. The test route consisted of a 10-mile piece of highway. The route was driven in both directions and data from the onboard fuel efficiency monitor were recorded.

The second test route, also, consisted of a set 10-mile piece of highway on Drycreek Road (Route B, Figure 8). The route was driven in both directions. The vehicle was accelerated from a standstill at wide-open throttle to 50 mph (Drycreek Rd) to eliminate variations introduced by driver behavior. At 50 mph, the cruise control was set for the duration of the drive.

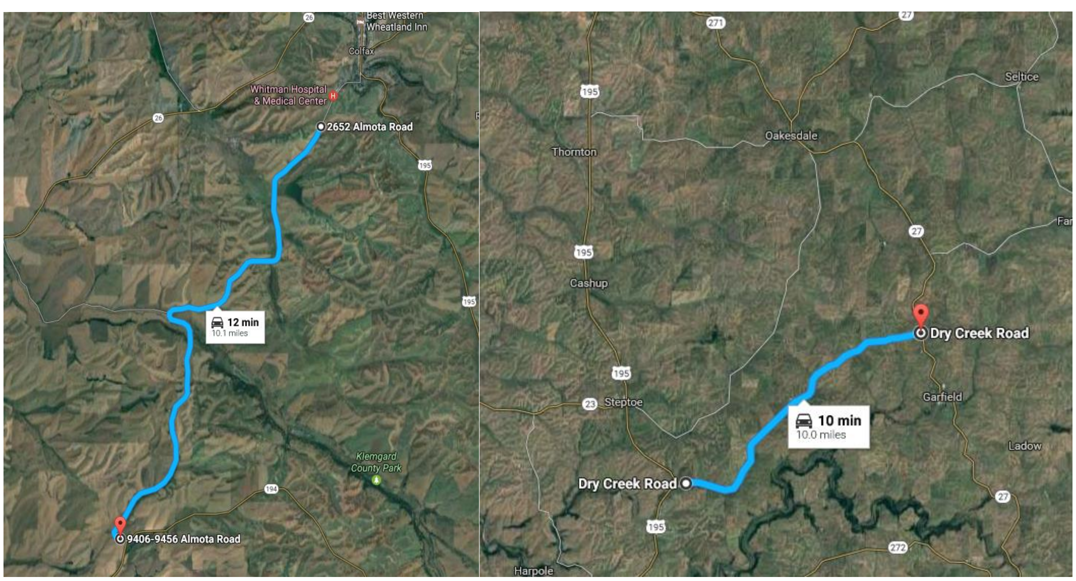


Figure 9. Google map of the routes driven: **Route A** Almota Road (left) and **Route B** Drycreek Road (right).

The load experienced by both vehicles was comparable and remained unchanged for the entire duration of testing. Before driving the test routes, test vehicles were warmed up to normal operating temperatures. To negate the potential effects changes in atmospheric temperature and pressure may have on measured fuel consumption, the intervals for alternating vehicles on a test route were maintained to be less than one hour. The test vehicles were refueled at the same time, at the gas station to mitigate any variability in fuel consumption/efficiency that may arise from differences in fuel. The route was driven in both directions and data from the onboard fuel efficiency monitor were recorded. Fuel economy metrics were taken from calculations performed by the onboard computer.

PRELIMINARY RESULTS FROM ALMOTA RD

The difference between the forward and backward routes however was substantial, due to a large change in elevation (from 2339.5 feet to 1983.6 feet). A significant difference in fuel efficiency (~25%) was observed between the two test routes, for both vehicles (See Figure 9). However, on both routes **the higher mileage Prius, treated with one application of the TriboTEX engine coating, proved to have approximately 4% higher fuel efficiency than the baseline vehicle with fewer odometer miles**.

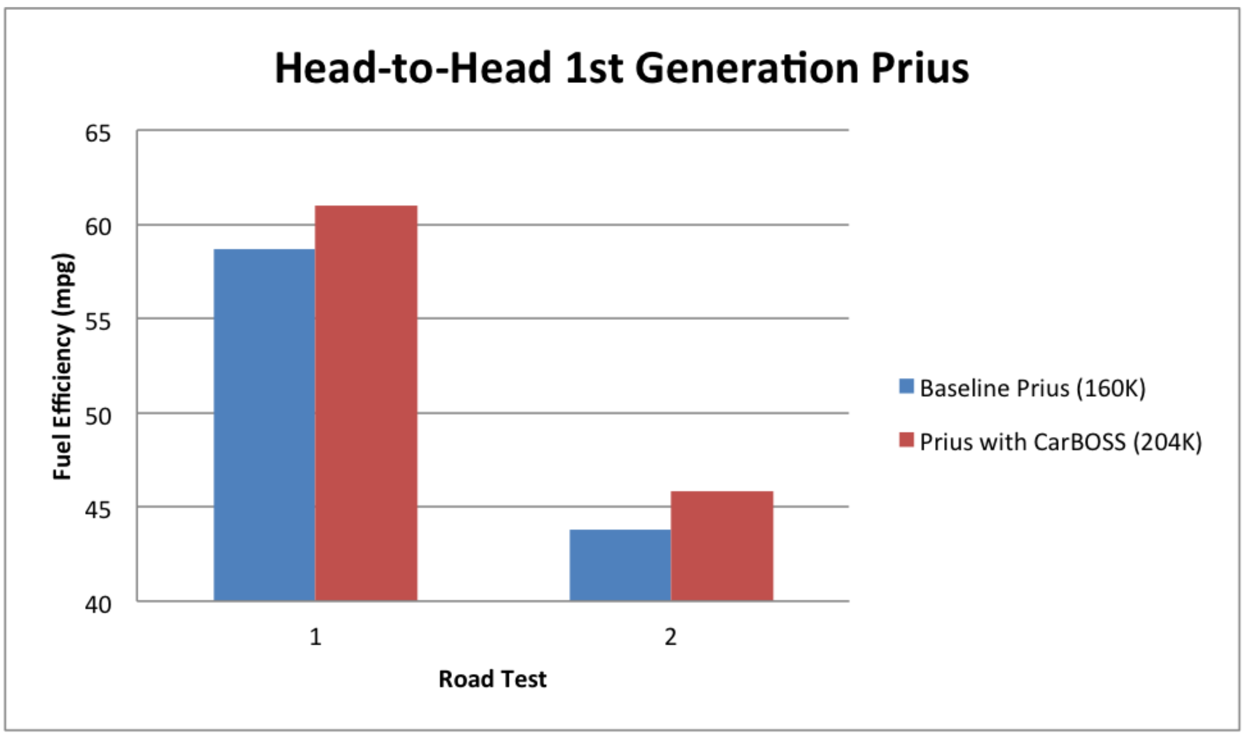


Figure 10. Results from preliminary testing on Almota Road. The blue bars represent the fuel efficiency measured in the baseline vehicle (blue Prius with 160K) for both the forward (Road Test 1) and the return (Road Test 2) trip. The red bars represent the fuel efficiency in the vehicle with added nanomaterial engine coating provided by TriboTEX (green Prius with 204K) for both the forward (Road Test 1) and the return (Road Test 2) trip.

RESULTS FROM DRYCREEK ROAD

The change in elevation on the second route was more gradual (from 2294.7 feet to 2528.5 feet). The ambient conditions (Table 5) before and after testing were recorded to identify if large discrepancies in atmospheric conditions were present.

Drycreek Road	Ambient Conditions	
Temperature	54 °F	51 °F
Humidity	61%	47%
Pressure	29.9 inHg	29.9 inHg
Wind Speed	5 NE mph	10 NE mph
Wind Chill (perception)	53 °F	50 °F
Time of Measurements	18:13	20:06

Table 5. Ambient conditions before and after testing on Drycreek Rd.

Fuel efficiency data for each of the trips (forward and backward) were averaged and standards of deviation were calculated. Differences in the average fuel efficiencies between the two vehicles were 5% for the return trip and 10% for the drive forward. **These results indicate that the test vehicle with the TriboTEX engine coating and higher odometer mileage performs better than the baseline vehicle**. As mentioned previously (see Passat Case Study) fuel efficiency is dependent on the route taken and ambient conditions.

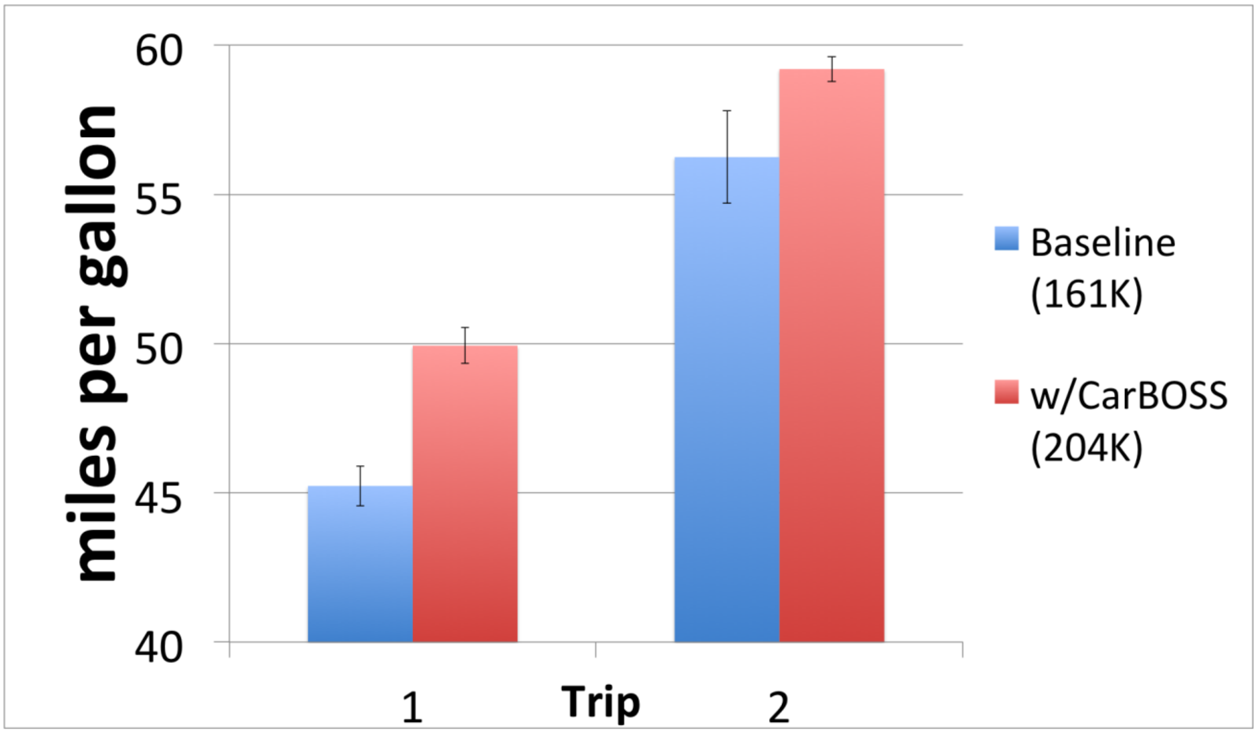


Figure 11. Fuel efficiency results from test drives on Drycreek Road. The blue bars represent the fuel efficiency measured in the baseline vehicle (blue Prius with 161K) for both the forward (Trip 1) and the return (Trip 2) trips. The red bars represent the fuel efficiency in the vehicle with added nanomaterial engine coating provided by TriboTEX (green Prius with 204K) for both the forward (Trip 1) and the return (Trip 2) trips. Standards of deviation, calculated from a set of trips in each direction, are indicated with the error bars.

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