ENGINEERING ANALYSIS CLOSING REPORT

<u>SUBJECT</u>: High-pressure fuel pump (HPFP) failure resulting in engine stall while driving.

<u>EA No.</u>: EA11-003 **<u>Date Opened</u>:** 7-Feb-2011 **<u>Date Closed</u>:** 27-Mar-2015

<u>BASIS</u>: On August 26, 2010, the Office of Defects Investigation (ODI) opened Preliminary Evaluation PE10-034 to investigate seven complaints alleging incidents of engine stall while driving in model year (MY) 2009 Volkswagen Jetta vehicles equipped with Volkswagen 2.0L TDI Clean Diesel engines.

ODI upgraded the investigation to an Engineering Analysis on February 7, 2011, based on 160 complaints to ODI and Volkswagen involving HPFP failures in MY 2009 through 2010 Volkswagen Jetta and Golf and Audi A3 TDI vehicles and questions regarding fuel sample results provided by Volkswagen as part of its response to PE10-034. During EA11-003, ODI analyzed design information, field experience and test data for MY 2009 through 2012 Volkswagen Jetta, Golf and Touareg and Audi A3 and Q7 vehicles equipped with TDI engines (Figure 1).

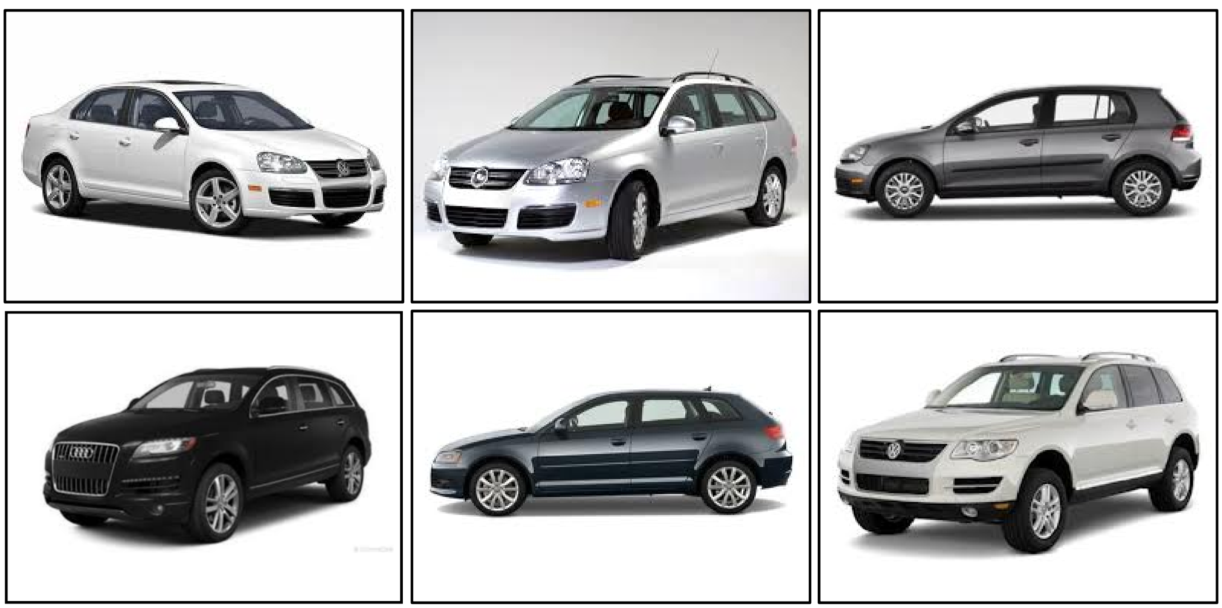

Figure 1. Subject TDI Vehicles, Clockwise from Upper Left: Volkswagen Jetta Sedan, Jetta SportWagen, Golf (4 door) and Touareg; Audi A3 and Q7.

When PE10-034 was opened, ODI had not identified a specific fuel system component responsible for the complaints of engine stall in the MY 2009 Jetta vehicles. As a result, ODI broadly examined complaints of engine stall related to fuel system failure in the MY 2009 Jetta vehicles and sent an information request letter to Volkswagen defining the alleged defect as “engine stalling and/or loss of motive power” and the subject component as “all TDI Clean Diesel fuel system components.” Volkswagen’s response to ODI’s information request identified the HPFP as the primary cause of customer concerns with stalling and loss of power related to the fuel system in MY 2009 Jetta TDI vehicles. Volkswagen further indicated that, apart from a limited number of failures related to manufacturing process issues in early production vehicles, HPFP failures could be attributed to vehicle operation with gasoline contaminated diesel fuel.

Volkswagen cited results from field tests performed on fuel samples taken from 43 vehicles which had experienced HPFP failures in August and September 2010. According to Volkswagen, the samples from 37 of the vehicles "clearly showed average contamination of 8.5% gasoline in the diesel fuel." However, ODI's review of the test results provided by Volkswagen determined that the average contamination for the 37 vehicles was actually 0.85% based on the data provided.[1] Based on questions regarding Volkswagen's fuel test results and complaints alleging stalls caused by HPFP failure with no prior misfuel, ODI upgraded the investigation to an Engineering Analysis.

<u>DESCRIPTION OF SYSTEM</u>: The subject vehicles are equipped with Volkswagen's 2.0L 4-cylinder and 3.0L 6-cylinder TDI Clean Diesel engines. Schematics of the fuel injections systems are shown in Figures A1 and A2 in the Appendix. The HPFP supplies fuel pressure and flow required for the Bosch common-rail piezo injection system (Figure 2). The engine control module (ECM) manages fuel pressure by actuating the Fuel Pressure Regulator Valve, the Fuel Metering Valve, or both, depending on operating conditions.

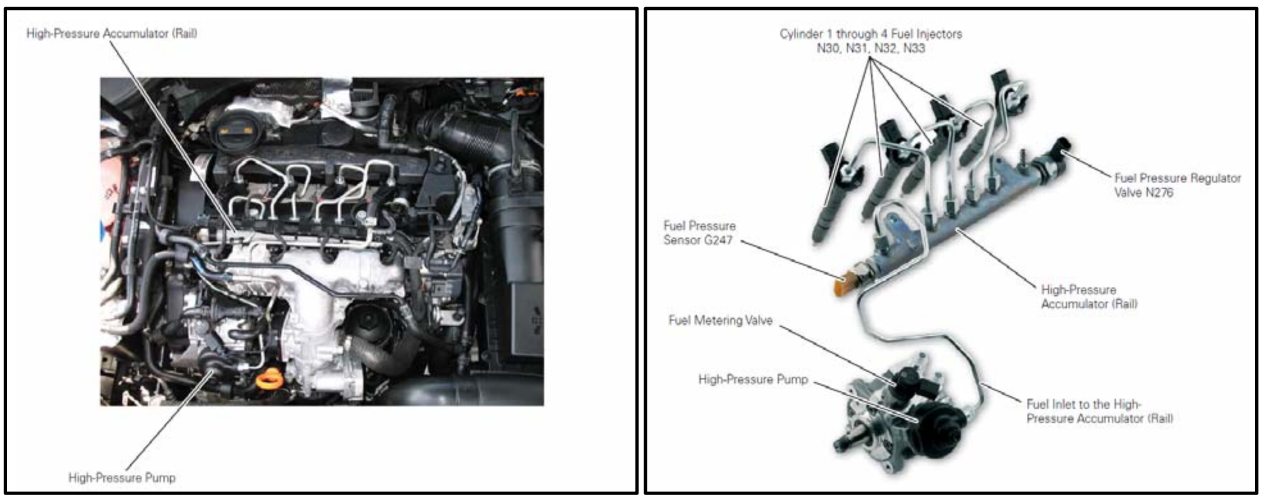

Figure 2. High Pressure Fuel Pump and Fuel Rail Assembly (2.0L 4-Cylinder Engine, CP4.1 Pump).

The subject HPFP's are Bosch tappet type pumps with a roller/cam drivetrain (Figure 3). The pumps were designed with an Anti-Wear Package, including enhanced roller and roller end coatings, for use with ultra-low sulfur diesel fuel sold in the United States[2]. Schematics of the HPFP showing the internal components and flow path are provided in Figures A3 and A4. If the pressure commanded by the ECM cannot be reached, system diagnostics will set a Rail Pressure Control fault (e.g., DTC P0087 – Fuel Rail/System Pressure- Too Low), which results in the Glow Plug Light flashing and a transition to Limp Home operating mode with reduced fuel pressure.

[1] The samples from only one vehicle showed evidence of potential gasoline contamination, with test results indicating approximately 10.6% gasoline. The other 36 vehicles cited by Volkswagen averaged 0.58% gasoline.
[2] ASTM D975 Grade No. 2-D S15 diesel fuel.

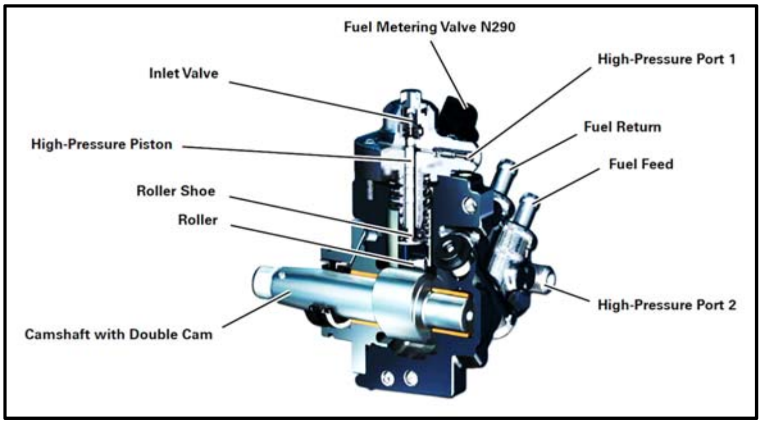

Figure 3. HPFP Components.

SUBJECT VEHICLES: Volkswagen produced just under a quarter million subject vehicles. Table 1 provides a breakdown of vehicles built by engine/pump, model and model year.[3]

Engine/ HPFP	Model	Model Year				Total
		2009	2010	2011	2012	
2.0L/ CP4.1	Jetta	37,889	53,088	42,477	51,538	184,992
	Golf	--	4,446	9,068	11,231	24,745
	Audi A3	--	2,180	3,791	3,865	9,836
	Total	**37,889**	**59,714**	**55,336**	**66,634**	**219,573**
3.0L/ CP4.2	Touareg	833	1,771	2,454	5,500	10,558
	Audi Q7	1,121	2,459	4,152	3,416	11,148
	Total	**1,954**	**4,230**	**6,606**	**8,916**	**21,706**
Total		**39,843**	**63,944**	**61,942**	**75,550**	**241,279**

Table 1. Subject Vehicle Production, by Engine/Pump, Model and Model Year.

PROBLEM EXPERIENCE: A summary of field data related to the alleged defect is provided in Table 2. All Volkswagen data in this report is through October 12, 2012, unless otherwise noted. The incidents counted by ODI in Table 2 exclude, to the extent possible based on NHTSA analysis of available records, HPFP replacements that did not involve drivetrain failure, HPFP failures that did not involve a stall claim, and incidents resulting from misfueling with gasoline.

Field Data		Source		Total
Category	**Type**	**ODI**	**VW**	
Incident reports	Consumer complaints	178	100	251
	Field reports	-	557	557
	Total reports (unique VINs)	178	562	713
Repair records	Warranty claims	-	623	623
Total (unique VINs)		178	1,093	1,255

Table 2. Field Data Summary (totals are for unique vehicles, excluding duplicates).

[3] In MY 2013 Volkswagen implemented misfuel guard protection in all vehicles equipped with CP4.1 and CP4.2 injection pumps, including certain Volkswagen Passat and Beetle vehicles equipped with 2.0L TDI engines. For the subject vehicles, only the MY 2009-2012 Audi Q7 vehicles were built with misfuel protection devices in the filler neck.

DESIGN CHANGES: Tables 3 and 4 summarize the design histories related to drivetrain components in the CP4.1 and CP4.2 pumps used in the subject vehicles.

Date	RP#	Change Description	Reason for Change
SOP	RP0	HPFP with Anti Wear Package (AWP) - C-Coating, reduced plunger clearance	Adaptation to US market low lubricity diesel fuel (RP0)
May 2009		Change of carbon coating at roller	Increase of robustness, eliminate blemishes on roller surface
Nov 2010	RP1	Changed carbon coating of roller and roller shoe, reduced radial roller clearance, and added suction valve strainer	Improvements against off-spec fuel in fuel critical foreign markets (RP1)
Nov 2011	RP1+	Changed carbon coating of roller and roller shoe and reduced radial tappet clearance	Further improvements against off-spec fuel in fuel-critical foreign markets (RP1+)
Nov 2012		Increased wire diameter of metering unit mesh strainer	Improve resistance to strainer deformation

Table 3. Design History, CP4.1 Pump.

Date	RP#	Change Description	Reason for Change
SOP	RP0	HPFP with Anti Wear Package (AWP) - C-Coating, reduced plunger clearance	Adaptation to US market low lubricity diesel fuel (RP0)
May 2009		Change of carbon coating at roller	Increase of robustness, eliminate blemishes on roller surface
Apr 2010	RP1	Changed carbon coating of roller and roller shoe, reduced radial roller clearance, and added suction valve strainer	Improvements against off-spec fuel in fuel critical foreign markets (RP1)
Nov 2010	RP2	Inlet & outlet of HPFP "swapped" and early activation of fuel supply pump	Improve cooling diesel oil flow, robustness improvement (RP2)
Nov 2010		Acoustic improved vent in the backflow	Acoustic improved vent in the backflow
Nov 2012		Relocation of the overflow valve to the pump outlet	Optimization of the de-airing

Table 4. Design History, CP4.2 Pump.

VOLKSWAGEN'S ASSESSMENT: Volkswagen has not identified any design or manufacturing defects in the subject TDI Clean Diesel pumps and has stated that the subject pumps were designed, tested and approved for use in the United States market, with substantial design margins for fuels that are out of specification. Volkswagen believes that misfueling with gasoline is the primary cause of HPFP drivetrain failures in the field. The company does not believe that HPFP drivetrain failure is likely to result in engine stall and, in incidents in which stalls do occur; they are preceded by multiple obvious symptoms associated with reduced engine fuel rail pressure and poor engine performance. Through December 2014, Volkswagen was not aware of any crashes or injuries related to HPFP failures in the subject vehicles.

VOLKSWAGEN FIELD ACTIONS: Volkswagen has taken several actions to address concerns with misfueling the subject vehicles, starting with technical bulletins issued to dealers in the Spring of 2010 with instructions for diagnosing and addressing use of incorrect fuel, a "Diesel Only" customer information campaign, and service campaigns to install devices in the fuel filler neck to prevent misfuel with gasoline.

Misfuel bulletins. On May 17, 2010, Audi issued technical service bulletin, TB A011008 2023360-1, to address concerns with engine performance, drivability and/or fuel delivery that may be caused by contaminated or incorrect fuel in MY 2010 A3 vehicles with 2.0L TDI engines and MY 2009-10 Q7 vehicles with 3.0L TDI engines. On June 8, 2010, Volkswagen issued TB V011011 2023624 to address similar concerns in MY 2009 through 2010 Jetta and MY 2010 Golf vehicles equipped with 2.0L TDI engines and MY 2009 through 2010 Touareg vehicles equipped with 3.0L TDI engines.

The bulletins listed multiple symptoms associated with contaminated or incorrect fuel, including malfunction indicator lamp (MIL) illumination, diagnostic trouble code P0087 (Rail fuel pressure too low), excess "rattling" noise from the engine ("diesel clatter"), no start or hard starting, loss of power while driving , and rust or metal debris found in the fuel system (Figure 4).

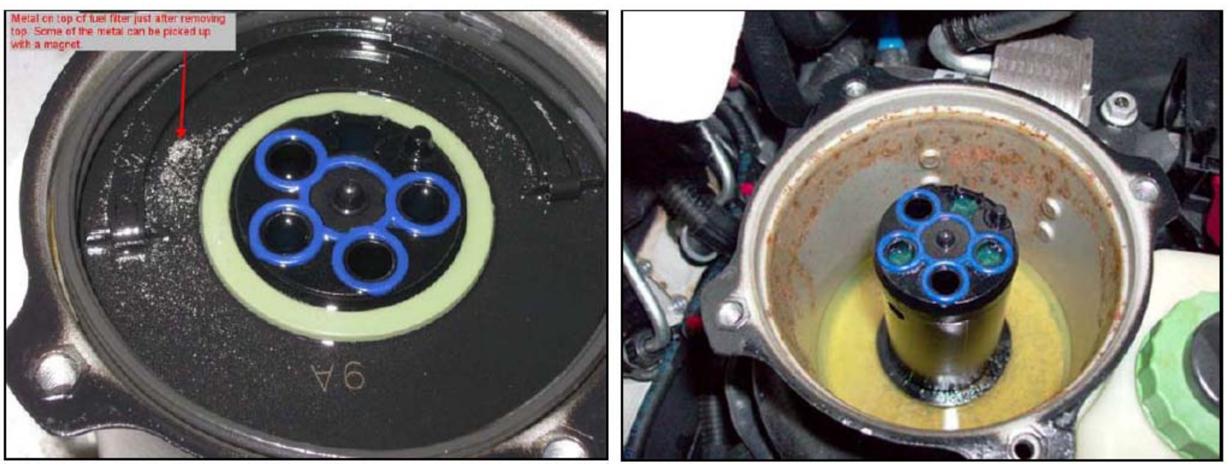

Figure 4. Examples of metal debris (left) and rust (right) in fuel filter housing inspection provided in Volkswagen and Audi service bulletins.

The bulletins identified water ingress into service station holding tanks, errors in fuel transport and incorrect fuel dispensed into the vehicle by customers or service station employees (i.e., misfuel) as possible causes of fuel contamination and indicated that "fuel system damage incurred by use of fuel not complying with ASTM-D-975 Grade 2 S15 (B5 or less biodiesel content) standards" would not be covered under warranty.

"Diesel Only" advisory. On July 10, 2012, Volkswagen initiated a "Diesel Only" customer advisory campaign, mailing letters to owners of subject vehicles with warnings against misfueling with gasoline. Volkswagen provided warning labels for customers to place in the area of the refueling door and cap (Figure 5), reminding operators to refuel with diesel fuel and that "even small amounts of gasoline can cause engine damage."

Figure 5. Volkswagen Diesel Only customer advisory warning labels.

Misfuel Guard campaign. About 10 months later, on May 21, 2013, Volkswagen launched Service Action Campaigns 20T8 (Volkswagen Jetta and Golf) and 20U3 (Audi A3) to contact owners and provide free installation of misfuel guard devices in the filler necks of subject vehicles with the 2.0L engines (Figures 6a and 6b). The vehicles with 3.0L engines were not included in the campaign because the Audi Q7 vehicles already had misfuel protection devices in the original vehicle design and the filler neck of the Volkswagen Touareg vehicles would not accommodate the addition of a misfuel guard device.

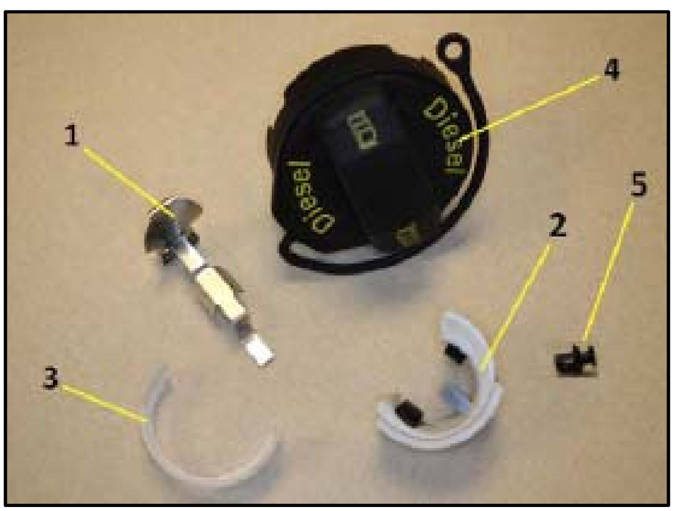

Figure 6a. Service Action Campaign kit: 1–Spring loaded flap insert, 2–Fuel filler lockout mechanism, 3–Plastic retaining ring, 4–Replacement fuel cap with tether, and 5–Mounting pin for fuel cap tether.

Figure 6b. Campaign kit installed in filler neck.

By November 2014, Volkswagen reported campaign completion in approximately 69 percent of the subject vehicles with 2.0L engines. Table 5 provides a breakdown of campaign completion rates by model and model year through early November 2014.

Campaign	Model	Model Year				Total
		2009	2010	2011	2012	
20T8	Jetta	58%	66%	69%	76%	68%
	Golf	-	62%	68%	77%	71%
20U3	A3	-	80%	82%	88%	84%
Total		58%	66%	70%	77%	69%

Table 5. Completion Rates through 11/14/2013 for Volkswagen Service Campaigns.

Metering valve inspection bulletins. In an effort to reduce unnecessary pump replacements, in March 2014 Volkswagen issued Technical Service Bulletins 2036656 (Volkswagen) and 2036668 (Audi) to change the requirements for replacing the HPFP when diagnosing driveability or engine stall complaints involving symptoms of MIL "on," rough running, no start or fuel rail pressure diagnostic trouble codes (DTC P0087 – Fuel Rail/System Pressure- Too Low, DTC P0088 – Fuel Rail/System Pressure – Too High, or DTC P0191 – Fuel Rail Pressure Sensor "A" Circuit Range/Performance).. The bulletin eliminates the requirement to replace the pump following removal of the N290 metering valve to inspect for metal particles/debris if the inspection results are negative (Figure 7).

Figure 7. Fuel metering valve and valve bore with metal particles (A); and without metal particles (B).

<u>FIELD DATA ANALYSIS</u>: ODI analyzed complaint, field return and warranty data to assess failure rates and trends associated with HPFP drivetrain failure and resulting engine stall while driving incidents. To the extent possible, ODI excluded incidents in which operator misfueling was clearly the cause of the pump replacement.

VRTC Review Process. ODI's data analysis was performed after an extensive review process by NHTSA's Vehicle Research and Test Center (VRTC) in East Liberty, Ohio. VRTC assisted ODI in reviewing field data, compiling and managing a large database of over 6,000 field incidents, reviewing engineering documents and other technical information provided by Volkswagen and Bosch, consulting with test laboratories and other independent experts in diesel fuel properties/testing, coordinating the collection and testing of diesel fuel samples from select samples of incident vehicles, and conducting tests to evaluate various misfuel evaluation methods used by Volkswagen dealer personnel.

ODI analyzed the VRTC database and data provided by Volkswagen to assess rates of pump drivetrain failures and related stall incidents by production date and design level. In addition, ODI analyzed fuel sampling and pump field return analysis data to evaluate Volkswagen's assessment that misfueling with gasoline was the primary cause for incidents of HPFP drivetrain failures in the subject vehicles.

Failure Rate Analysis. VRTC's analysis of data submitted by Volkswagen through early October 2012 identified 3,932 incidents of HPFP drivetrain failures that were not associated with an admitted misfuel or fuel test results indicating a misfuel. The rates by pump and vehicle model are shown in Table 6.

Engine/ HPFP	Model	Vehicles Produced	Vehicle Exposure (Veh Yrs)	HPFP Drivetrain Failures	Failure Rate (IPTV)	Exposure Adj Rate (IPTVY)
2.0L/ CP4.1	Jetta	184,992	356,154	3,178	17.2	8.9
	Golf (A6)	24,745	30,096	272	11.0	9.0
	Audi A3	9,836	15,069	155	15.8	10.3
	Total	**219,573**	**401,319**	**3,605**	**16.4**	**9.0**
3.0L/ CP4.2	Touareg	10,558	13,593	123	11.6	9.1
	Audi Q7	11,148	19,871	204	18.3	10.3
	Total	**21,706**	**33,464**	**327**	**15.1**	**9.8**
Total		**241,279**	**434,783**	**3,932**	**16.3**	**9.0**

Table 6. HPFP Drivetrain Failure Rates by Engine/Pump and Vehicle Model.

Analysis of all data sources identified 1,255 incidents related to the alleged defect, engine stall resulting from HPFP drivetrain failure that did not involve evidence of misfueling (Table 7). The stalling data is a subset of HPFP drivetrain failure counts in Table 6, which also include incidents involving allegations of no start, driveability and warning lamp illumination symptoms, as well as many in which the symptoms and consequences of the failure were not known.

After adjusting for exposure, stalling rates are similar for each of the subject models ranging from 2.36 to 3.24 incidents per thousand vehicle years (IPTVY). The overall exposure adjusted rate is 2.89 IPTVY, which would result in a stalling rate of approximately 0.9 percent at 3 years in service. There have been no confirmed crashes, injuries or fatalities related to the alleged defect.

Engine/ HPFP	Model	Vehicles Produced	Vehicle Exposure (Veh Yrs)	Stalling Incidents	Stalling Rate (IPTV)	Exposure Adj Rate (IPTVY)
2.0L/ CP4.1	Jetta	184,992	356,154	1,032	5.6	2.9
	Golf (A6)	24,745	30,096	71	2.9	2.4
	Audi A3	9,836	15,069	48	4.9	3.2
	Total	**219,573**	**401,319**	**1,151**	**5.2**	**2.9**
3.0L/ CP4.2	Touareg	10,558	13,593	44	4.2	3.2
	Audi Q7	11,148	19,871	60	5.4	3.0
	Total	**21,706**	**33,464**	**104**	**4.8**	**3.1**
Total		**241,279**	**434,783**	**1,255**	**5.2**	**2.9**

Table 7. HPFP Drivetrain Failure Engine Stall Rates by Engine/Pump and Vehicle Model.

Table 8 provides a breakdown of misfuel event counts and rates by engine/pump and model. The data show a clear difference between the Audi Q7, which was sold with a misfuel protection device in the filler neck, and the rest of the subject vehicles which were not built with misfuel protection devices. The Q7 exposure adjusted rate of 0.25 incidents per thousand vehicle years is almost an order of magnitude lower than the combined rate for the remaining subject vehicles (2.40 IPTVY). Additional analysis by manufacturing date and pump design level is provided in the analysis section of this report. As previously noted, analysis of failures by model and engine/pump did not find any significant differences in field experience, apart from lower misfuel rates for the Audi Q7 vehicles with misfuel prevention devices included since the MY 2009 launch.

Engine/ HPFP	Model	Vehicles Produced	Vehicle Exposure (Veh-Yrs)	Misfuels	Misfuel Rate (IPTV)	Exposure Adj Rate (IPTVY)
2.0L/ CP4.1	Jetta	184,992	356,154	850	4.6	2.4
	Golf (A6)	24,745	30,096	50	2.0	1.7
	Audi A3	9,836	15,069	54	5.5	3.6
	Total	**219,573**	**401,319**	**954**	**4.3**	**2.4**
3.0L/ CP4.2	Touareg	10,558	13,593	41	3.9	3.0
	Audi Q7	11,148	19,871	5	0.4	0.2
	Total	**21,706**	**33,464**	**46**	**2.1**	**1.4**
Total		**241,279**	**434,783**	**1,000**	**4.1**	**2.3**

Table 8. Misfuel Rates by Engine/Pump and Vehicle Model.

Analysis of HPFP drivetrain failures and related stalls by month of production shows elevated rates in the early production ramp-up period for the Jetta vehicles (Figures A5 and A6). No obvious changes in field experience corresponding with drivetrain design changes are evident, although the data was limited for the most recent design release when this data was captured in late 2012.

Design level. Analysis of HPFP drivetrain failure and related stalling rates by time in service for each of the three design levels for the CP4.2 pumps shows slightly higher rates for the RP1 design for HPFP drivetrain failures (Figure A7), but no significant difference when filtered for engine stall

(Figure A8). In a November 2014 review with ODI, Volkswagen indicated that its age-adjusted analysis of updated field data, including statistical forecast modeling of failure rates by time-in-service, found minimal differences in pump performance by design level.

Vehicle testing. Volkswagen conducted vehicle testing with varying amounts of gasoline misfueling to study the effects on engine performance and HPFP wear. The tests showed that increased levels of gasoline will lead to driveability symptoms, such as engine stumbling, stuttering, misfiring or rough running. According to Volkswagen, these symptoms start to become noticeable at levels of gasoline misfueling of 50 percent. At levels of 80 percent[4] and above, Volkswagen indicated that driveability issues worsen until the diesel engine will no longer run due to the interruption of the combustion process. At very high levels of misfueling (80-85%), test vehicles exhibited obvious knocking noise within a few seconds after starting the vehicle and showed a significant reduction in engine response and transition to limp mode operation in less than a mile after attempting to accelerate to highway speeds. No performance problems were observed in 378 miles of test driving a vehicle with 5% gasoline added to the diesel fuel and Volkswagen has indicated that operation with small amounts of gasoline contamination should have no effect on HPFP durability. No damage to the HPFP's were observed by Volkswagen after misfuel tests with either low or high amounts of gasoline misfueling.

Pump failure effects. ODI evaluated the effects of HPFP drivetrain failure on engine performance by: 1) reviewing Volkswagen's descriptions of the failure mechanism and effects; 2) analyzing ODI complaint narratives combined with follow-up interviews, when necessary; 3) analyzing diagnostic data retrieved by Volkswagen from some ODI complaint vehicles; and 4) reviewing the results of Volkswagen testing of a vehicle with a pre-damaged pump roller.[5]

According to Volkswagen, drivetrain wear results in gradual reductions in fuel pressure due to decreased pump plunger displacement. In addition, as wear progresses metal is abraded from drivetrain surfaces forming small flakes that are circulated throughout the fuel system. Particles caught in the metering unit strainer cause a pressure drop, which results in a fault code and warning light. Volkswagen states that the rate of wear "depends on the properties of fuel being used as well as pump load conditions." Several of the pump failures in parts returned to ODI, or documented during inspections by Bosch or by some consumers, displayed failures caused by rollers rotating 90 degrees relative to the cam, resulting in a distinct abrasive wear pattern in the center of the cam. Figure 8 shows the Bosch self-stabilizing design and drivetrain damage resulting from roller rotation in an ODI complaint vehicle that reported experiencing a sudden decrease in engine power resulting in speed dropping from 70 mph to 50 mph, as the vehicle entered limp mode less than a minute after the engine light and then glow plug lamp illuminated (VOQ 10354434).

[4] Volkswagen indicated that a fuel tank mixture of 80% gasoline and 20% diesel would result from refueling with gasoline shortly after the low fuel warning light has illuminated.
[5] As previously noted, Volkswagen was not able

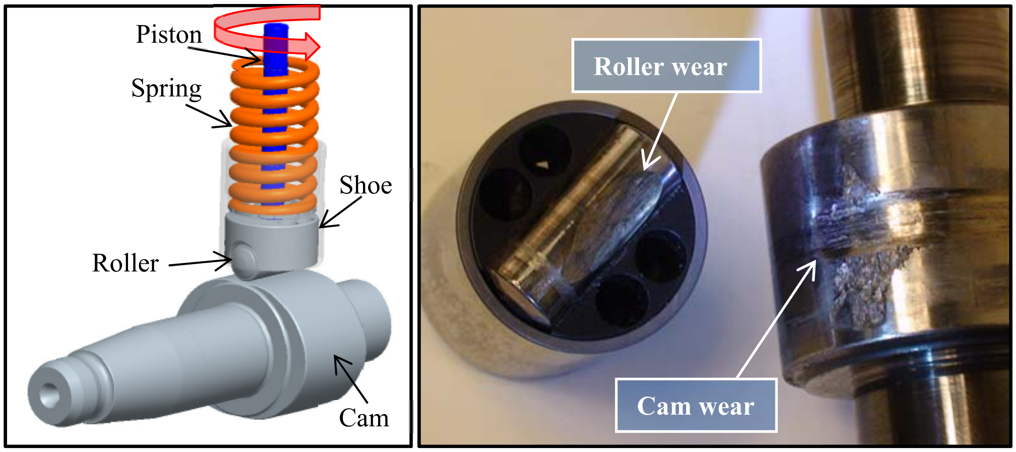

Figure 8. Bosch self-stabilizing roller (left). Roller and cam damage resulting from rotation of the roller; MY 2009 Jetta, RP0 pump, 06/08 vehicle build (right).

Volkswagen provided ODI with Diagnostic Fault Log data from 121 ODI complaint vehicles alleging HPFP failures resulting in engine stall while driving. The diagnostic data shows time and/or mileage travelled between diagnostic trouble codes logged in memory. ODI's analysis of these complaints identified 85 alleging stall while driving, including 9 (10.6%) alleging that the stall occurred suddenly with no warning. The Diagnostic Fault Log data for these vehicles indicated that warning symptoms (DTC P0087, glow plug light, chime and limp mode) were available for all 85 (100%) and that the symptoms were present for at least one mile of driving in at least 58 (68.2%) of the vehicles, including 5 (55.6%) of the allegations of sudden failure; for over 5 miles in at least 34 (40.0) of the vehicles, including 4 (44.4%) of the allegations of sudden failure; and for over 60 miles in 10 (11.8%) of the vehicles, including 1 (11.1%) of the allegations of sudden failure.

A Volkswagen test of a vehicle with a flat spot machined onto the roller of the HPFP drivetrain was able to reproduce extended operation in limp mode. After a 23 minute warm-up at idle, this vehicle entered limp mode (with warning light) when initially accelerating to 50 mph and continued to operate in limp mode for another 43 minutes (36 miles) before the test was suspended.

FUEL TESTING

Initial VW field testing (2010). In its December 1, 2010 response to ODI's information request letter for PE10-034, Volkswagen provided data from its initial efforts to test fuel samples from vehicles repaired for HPFP failures. Volkswagen decided to purchase "specific testing equipment in August 2010 for precise and timely identification of fuel contamination for the workshops without the need for a time consuming analysis in a testing laboratory."[6] Volkswagen provided this data in a table showing the content of gasoline, biodiesel and water in parts per million (ppm) for 3 measurements per sample. Volkswagen summarized the test data as follows:

[6] Volkswagen purchased Integrated Portable Analyzer for Lubrication (iPAL) test devices for conducting early attempts at field testing of fuel samples. The iPAL testers are described in product literature as "an extremely small mid-IR fingerprint region spectrometer."

"The table shows the results for 49 vehicles' samples as follows:

- *In 4 cases the customer stated or admitted to have used gasoline instead of diesel*
- *In 2 instances gasoline was used by mistake at a dealership sales department or during pre-delivery inspection*
- *In 43 cases, a sample was taken and analyzed from the fuel tank of the affected vehicle*
- *Only 6 samples showed no or negligible amounts of gasoline in the sample, while one showed approximately 2.5% water in the fuel*
- *The remaining 37 samples clearly showed average contamination of 8.5% gasoline in the diesel fuel*

In summary, nearly 90% of the vehicles evidenced gasoline contaminated diesel fuel to be the cause of the failure."

Examination of the data provided by Volkswagen determined that the "average contamination of 8.5% gasoline" in the 37 vehicles with the highest measured gasoline content was a miscalculation and the actual average for those vehicles was 0.85%. For the 43 vehicles with fuel test data provided, 1 vehicle showed an average gasoline content of approximately 10.6%, 4 samples were between 1.11% and 1.51%, and the remaining 38 were all less than 1.0%. These results did not point to gasoline contamination as a cause of fuel pump failures in those vehicles, which was a factor in ODI's decision to upgrade the investigation to an Engineering Analysis in February 2011. Volkswagen discontinued its use of iPAL equipment as of September 30, 2010 after determining that the devices did not meet its requirements. In April 2011, Volkswagen began collecting fuel samples from vehicles serviced for fuel system concerns for testing by a laboratory.[7]

VW Study (2011-2014). In March 2011, shortly after EA11-003 was opened, Volkswagen initiated a study ("Workshop Program") to collect HPFP's and fuel samples from incident vehicles and to study properties of fuel sampled from sets of diesel fuel stations and randomly selected subject vehicles. Table 9 summarizes field and test data submitted by Volkswagen in EA11-003, including the counts for VW's classification of incidents for misfuel and engine stall[8].

Submission	Date	Incident Data (complaints, field reports, claims, lawsuits, warranty)			Fuel Sample Analysis	Returned Part Analysis	Part Sales
		Total	Misfuels	Stalls			
Original response	16-Dec-2011	1,443	510	206	431	102	1,873
Update #1	30-Nov-2012	6,147	2,102	1,232	827	301	6,057
Update #2	30-Oct-2013	6,628[9]	2,290	1,381	1,339	446	11,138
Update #3	17-Nov-2014	n/a	n/a	n/a	3,246	882	17,339

Table 9. Volkswagen Workshop Program Data Submission Summary.

[7] Volkswagen's fuel sample testing was performed by Inspectorate America Corporation – IAC Linden.
[8] Available complaint, field report and warranty records were analyzed by Volkswagen and VRTC to identify incidents resulting from misfuel with gasoline and incidents that resulted in stall while driving.
[9] Volkswagen's second update provided additional incident data summaries and categorizations only for incidents in which there was a fuel sample result or a returned pump analysis 8D report.

"Workshop Program" fuel testing. As of October 2013, Volkswagen had submitted data to ODI from fuel sample testing of 305 filling stations, 318 randomly selected vehicles, and 1,339 incident vehicles. As previously noted, Volkswagen has identified misfueling with gasoline as the primary cause of HPFP drivetrain failures in the subject vehicles. Volkswagen indicated that viscosity was the best indicator of gross misfueling (Figure 9) and also a critical fuel property for maintaining HPFP drivetrain integrity.

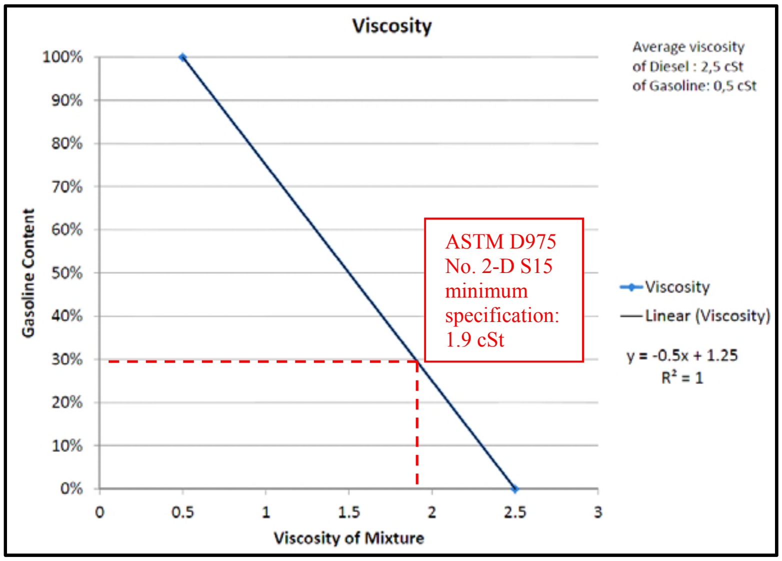

Figure 9. Volkswagen Viscosity Exhibit.

ODI analyzed the fuel test results for the control groups (fuel stations and random vehicles) and for the incident vehicles. The incident vehicle test results were analyzed separately for incidents classified by Volkswagen and misfuels and those in which misfuel was not indicated. ODI also compared misfuel with non-misfuel incidents based upon whether misfuel was indicated in the test results[10].

Fuel property	Fuel station survey	Random vehicle survey	Misfuel by VW Classification		Misfuel by Fuel Sample Testing[6]	
			Yes	No	Yes	No
Total samples	305	318	456	881	221	1,116
Kinematic viscosity < 1.9 cSt	0.7%	0.0%	50%	0.5%	100%	1.0%
Flash point < 52°C	9.5%	6.9%	63%	4.5%	100%	9.5%
Biodiesel > 5%	9.5%	9.1%	12%	6.1%	5.0%	8.7%
Water > 0.05	1.0%	1.3%	3.5%	1.0%	4.5%	1.3%
Lubricity wear scar > 520 µm	6.2%	2.8%	10.5%	3.4%	8.1%	5.4%

Table 10. Fuel Sample Group Comparison, Percentage of Out of Specification Results.

Analysis of field data, fuel sample and returned part analysis data from Volkswagen's workshop program and part sales data has not found evidence that misfueling with gasoline is the cause of

[10] Misfuel determined by fuel samples with: 1) kinematic viscosity < 1.9 cSt; and 2) flash point ≤ ambient temperature.

HPFP drivetrain failures in cases where the operator denies misfueling. Fuel samples from vehicles in which misfueling was acknowledged in complaint or repair records showed significantly different properties than samples from vehicles in which the operator denied misfueling (Table 10).

Viscosity test data for vehicles with pumps replaced in Volkswagen's Workshop Program that were not classified as acknowledged misfueling incidents are similar to the data from the two control groups (Table 10 and Figure A9). The results for the vehicles Volkswagen classified as misfuels were significantly different. The results also indicate that many of the vehicles Volkswagen classified as misfuels did not show evidence of gasoline in the test data. The differences between workshop misfuel and non-misfuel data sets are even more evident when the misfuel incidents are determined by fuel test results (Table 10 and Figure A10).

Figures A11 and A12 provide comparisons of the fuel sample groups for other fuel properties of interest, again showing that the workshop vehicles with no indication of misfuel were most similar to the results observed in the fuel station and random vehicle control groups.

Returned part analysis. Volkswagen submitted information from laboratory inspections of 446 fuel pumps returned from the field as part of the workshop program[11]. Approximately 8 percent of the 446 pumps examined in the Workshop Program were not the original pumps in the vehicles based on comparison of pump and vehicle manufacture dates, indicating prior pump replacements for those vehicles. Drivetrain failure was observed in slightly under half of the pumps examined and a similar number of inspections found the pumps were still functional, with most of these categorized as "No Trouble Found." The earliest design level pumps (RP0) had the highest percentage of drivetrain failures (66%) and the lowest percentage of functional pumps (30%).

	Pump Design Level			
Pump Failure Mode	**RP0**	**RP1**	**RP1+/ RP2**	**Total**
Drivetrain failure	100	84	31	215
Other failure	5	6	9	20
NTF/functional	44	121	46	211
Total	149	211	86	446
% Drivetrain	67%	40%	36%	48%
% NTF/functional	30%	57%	54%	47%

Table 11. Pump Failure Modes by Design Level, Returned Part Analysis.

Deposits (e.g., gum, corrosion) were observed on the drivetrain components in approximately half of the pumps with drivetrain failures (108 of 214)[12] and the remaining drivetrain failures were classified as "mechanical/hydraulic" faults, with "no determination possible" as to cause. In either case, Volkswagen assessed the cause of failure as damage resulting from unsuitable fuel (i.e.,

[11] The pump inspections were performed by the pump supplier, Bosch.
[12] Ratios of deposits/corrosion observed in pumps with drivetrain failure were similar for each design level.

"misfuel" per Volkswagen's definition).[13] Table 11 provides a summary of the pump inspection results by pump design level. Table 11a in the Appendix provides this analysis for pumps from vehicles that Volkswagen did not classify as misfuel incidents and Table 11b does the same for pumps from vehicles Volkswagen did classify as misfuel incidents.

Approximately 45 percent (202 of 446) of the pumps with returned part analysis reports also had fuel sample test results. Analysis of the pump failure modes by indication of misfuel found that pumps from vehicles involved in misfuel incidents based on the fuel sample test results were not likely to experience drivetrain failure (6%) and were likely to have no trouble found or be functional (90%). Pumps from vehicles in which the test results did not show evidence of misfuel had a much higher likelihood of drivetrain failure (64%). Table 12 provides a summary of pump failure modes by misfuel group, as determined from fuel test results. Tables 12a-c in the Appendix provide breakdowns for each pump design level.

	All Pumps			
Pump Failure Mode	**Misfuel**	**No Misfuel**	**Total**	**% Misfuel**
Drivetrain failure	3	96	99	3%
Other failure	2	4	6	33%
NTF/functional	46	51	97	47%
Total	51	151	202	25%
% Drivetrain	6%	64%	49%	
% NTF/functional	90%	34%	48%	

Table 12. Pump Failure Mode by Fuel Sample Result, All Pumps.

Part sales. Analysis of HPFP part sales trends does not appear to show any influence from Volkswagen's implementation of misfuel prevention devices in production in MY 2013 starting in the summer of 2012, from Volkswagen's Diesel Only owner advisory program, from the more recent service campaign to add such devices to most of the subject vehicles that were sold without them, or from the revisions to repair procedures in early-2014 that were intended to eliminate the requirement to replacement pumps that were not damaged simply because the metering valve had been removed to inspect for metal particles. The part sales show a seasonal influence with sales increasing in summer months each year and a progressively increasing rate of sales per total vehicles in service (Figures A13 and A14).

Table 13 shows the basic reasons for HPFP replacement in the subject vehicles and the estimated breakdown of pump replacements and failures based on part return and fuel sample analysis data provided by Volkswagen.[14] To the extent possible, ODI's investigation was limited to drivetrain

[13] In a January 21, 2014 e-mail, Volkswagen indicated that results of laboratory analysis of the deposits/corrosion "determined that the typical causes are water, aged fuel, and fuel additives."

[14] Estimated percentages are based on ODI analysis of Volkswagen field return and fuel sample test data (see Tables 12 and 13). It should be noted that Volkswagen field return analysis data is not necessarily a representative/random sampling of all pump returns/replacements as the rate of samples with results consistent with gross misfueling with

failures resulting in engine stall which are a subset of category F1. Most of these failures are not associated with any evidence of a gross misfueling event. Failures resulting from fuel quality issues, including factors Volkswagen identified as likely causes of deposits observed in pumps with drivetrain failures, will not be prevented by the addition of misfuel guards.

Reason	Subcategory	ODI Code	Estimated Percentages	
			Pump Failures	**Pump Replacements**
Pump failure	Drivetrain failure indicated by metal debris in N290 metering valve with no indication of significant gasoline misfuel in fuel sample testing	F1	88.5%	46.6%
	VW repair procedure for gasoline misfuels resulting in pump drivetrain failure indicated by metal debris in metering valve (VW Scenario 3)	F2	3.0%	1.6%
	Other pump failures (e.g., metering valve, pressure regulating valve, piston return spring, check valve)	F3	8.5%	4.5%
Repair procedure	VW repair procedure for misfuel with gasoline followed by engine crank/start and no evidence of pump damage (Scenario 2)	P1	n/a	22.4%
	VW repair procedure requiring pump replacement when metering valve is removed to inspect for metal debris (when no debris is found)	P2	n/a	24.9%

Table 13. HPFP Replacement Categories.

The continuing pump sales trend after Volkswagen's various actions indicate that drivetrain failures may be a higher percentage of total failure than shown in Table 13. HPFP drivetrain failure results in contamination of the fuel system with metallic debris, so repair requires replacement of all or most fuel system components (e.g., fuel rail, injectors, fuel tank, in-tank delivery pump, auxiliary pump, fuel filter and fuel pipes) in addition to the failed HPFP and is very costly (frequently over $10,000).

REASON FOR CLOSING: ODI's analysis of HPFP drivetrain failure incidents indicates that most failures do not result in engine stall while driving and, when pump drivetrain failure does result in stall while driving, it is usually preceded by numerous warning symptoms (e.g., glow plug warning lamp, chime, limp mode, and driveability symptoms). The failure data for the subject vehicles show relatively low stalling rates (less than one percent at three years in service) for each of the pump designs used in the subject vehicles. There have been no reports of crashes, injuries or fatalities related to the alleged defect. Based on these facts, this investigation is closed. The closing of this investigation does not constitute a finding by NHTSA that a safety-related defect does not exist. The agency will continue to monitor complaints and other information relating to the alleged defect in the subject vehicles and take further action in the future if warranted.

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gasoline (kinematic viscosity < 1.9 cSt and flash point below ambient temperature) was 52% higher in pump returns with fuel sample results available (25.2%) than in the total set of fuel sample test results (16.6%).

APPENDIX

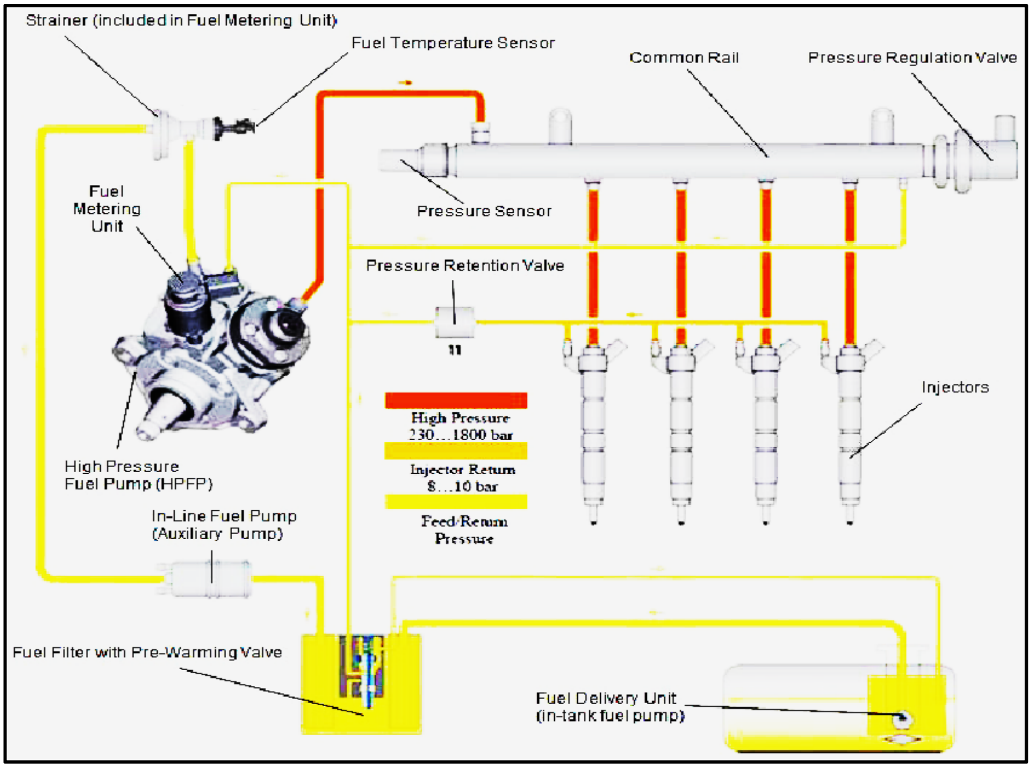

Figure A1. 4-Cylinder Fuel System Schematic.

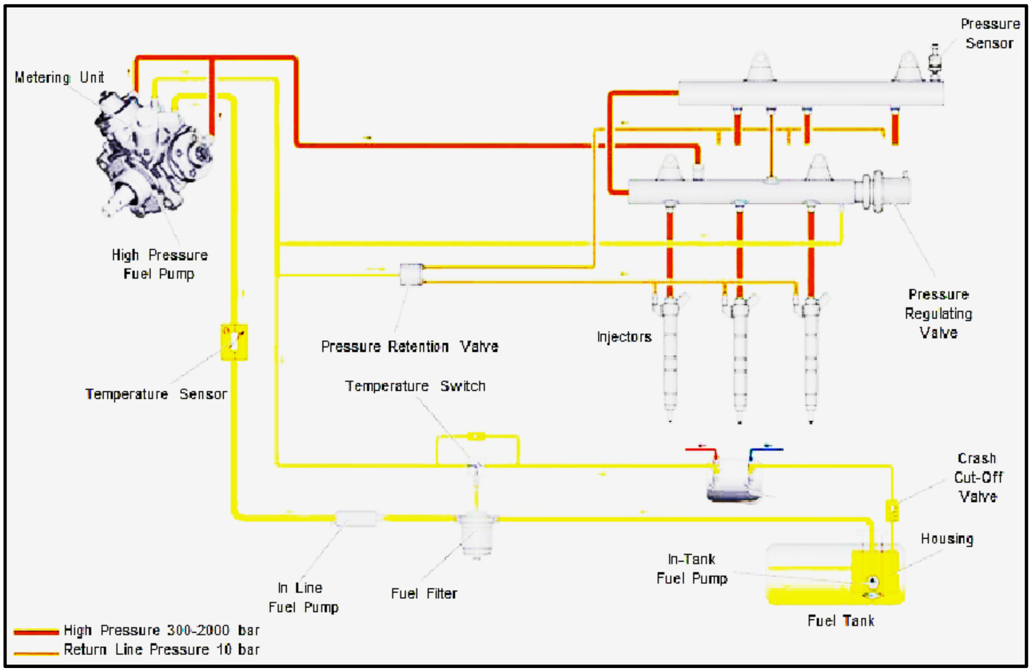

Figure A2. 6-Cylinder Fuel System Schematic.

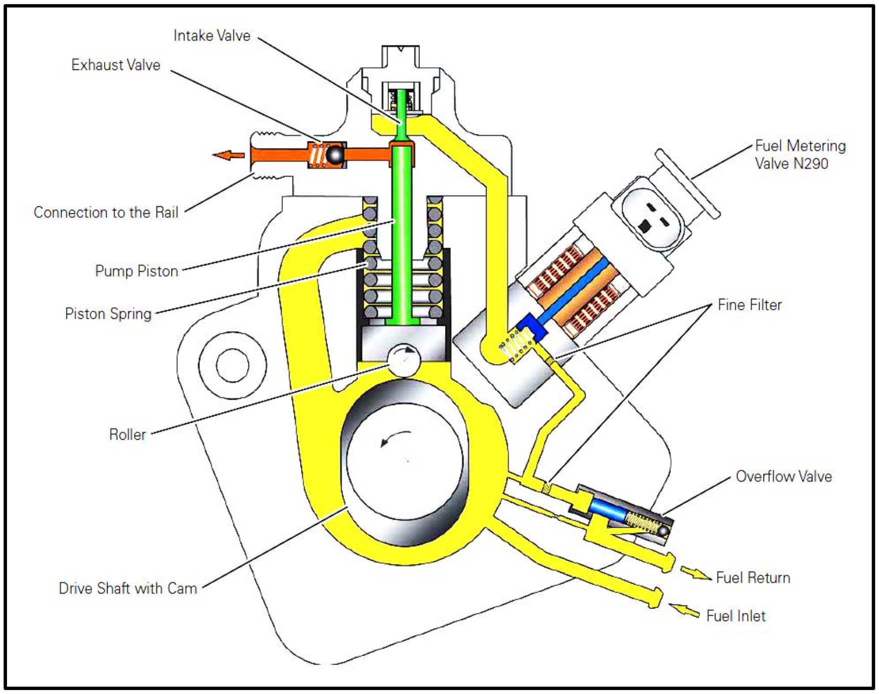

Figure A3. CP4.1 Pump Schematic.

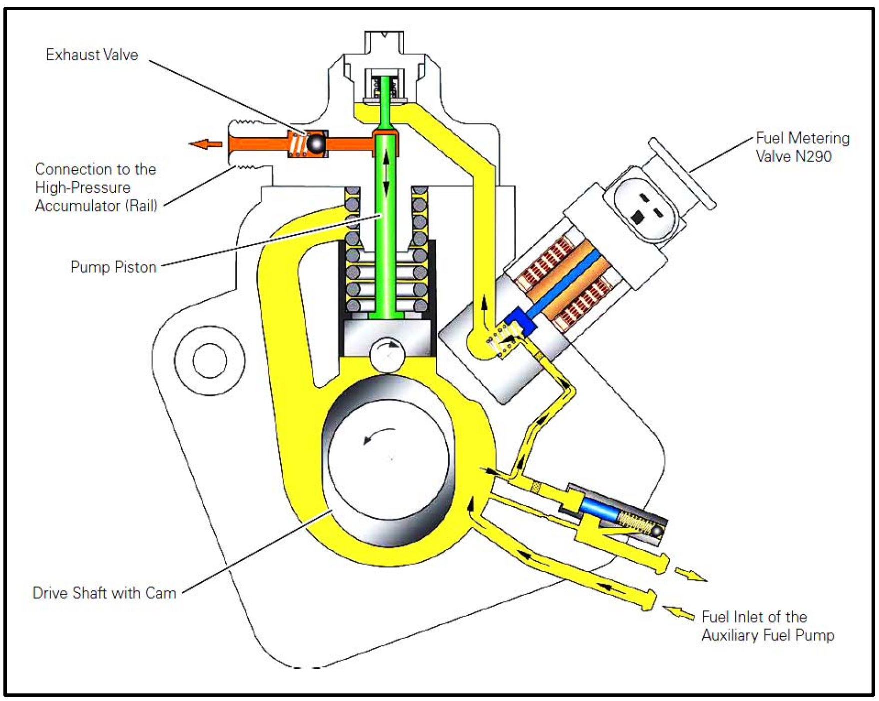

Figure A4. CP4.1 Pump Operation.

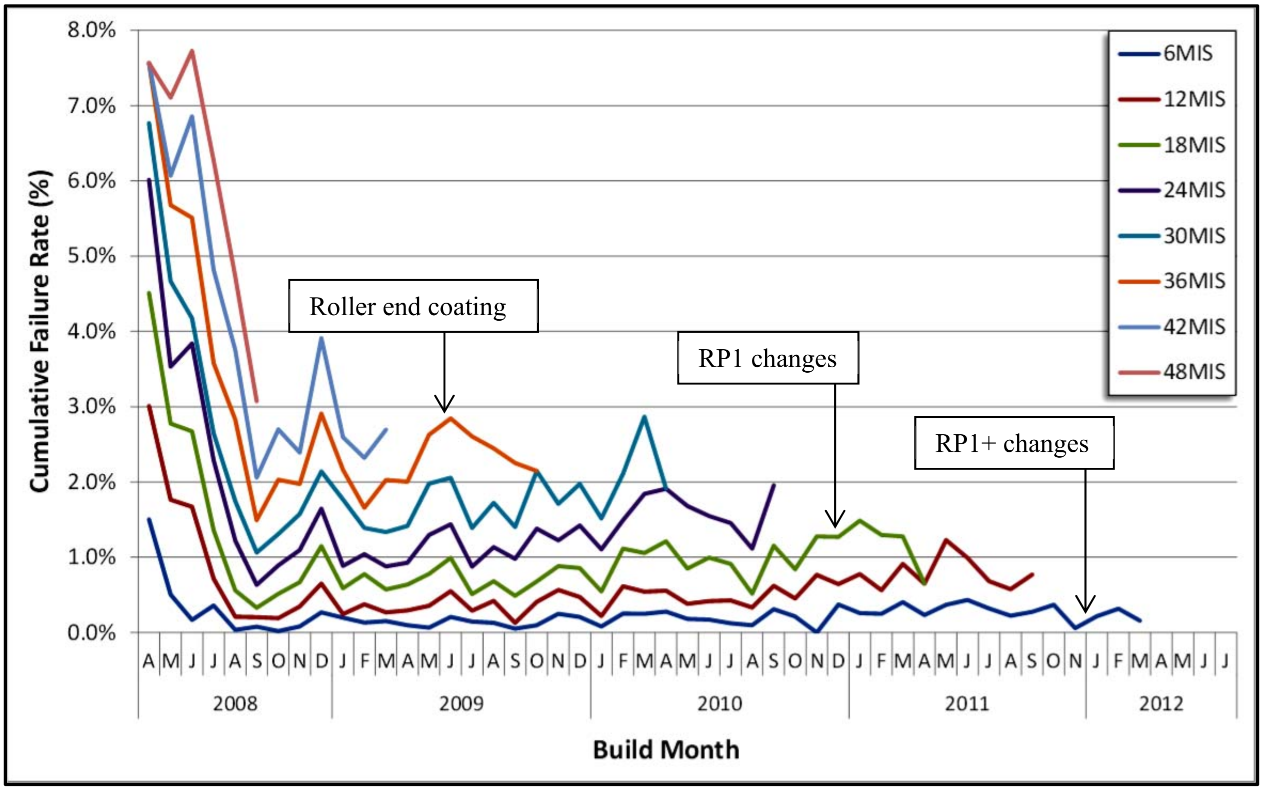

Figure A5. Cumulative Failure Rates by Build Month, HPFP Drivetrain Failures, Excluding Known Misfuels (CP4.1 pumps).

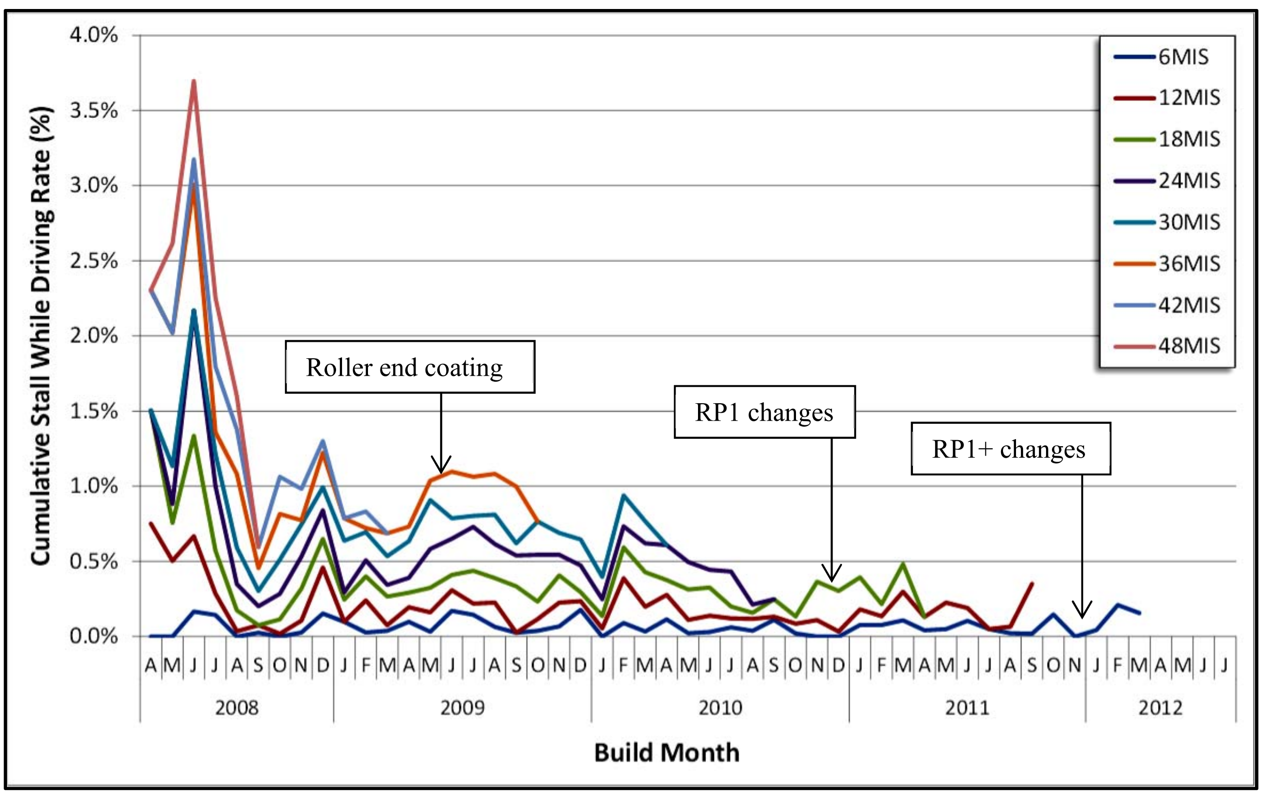

Figure A6. Cumulative Stall Rates, HPFP Drivetrain Failures, Excluding Known Misfuels (CP4.1 pumps).

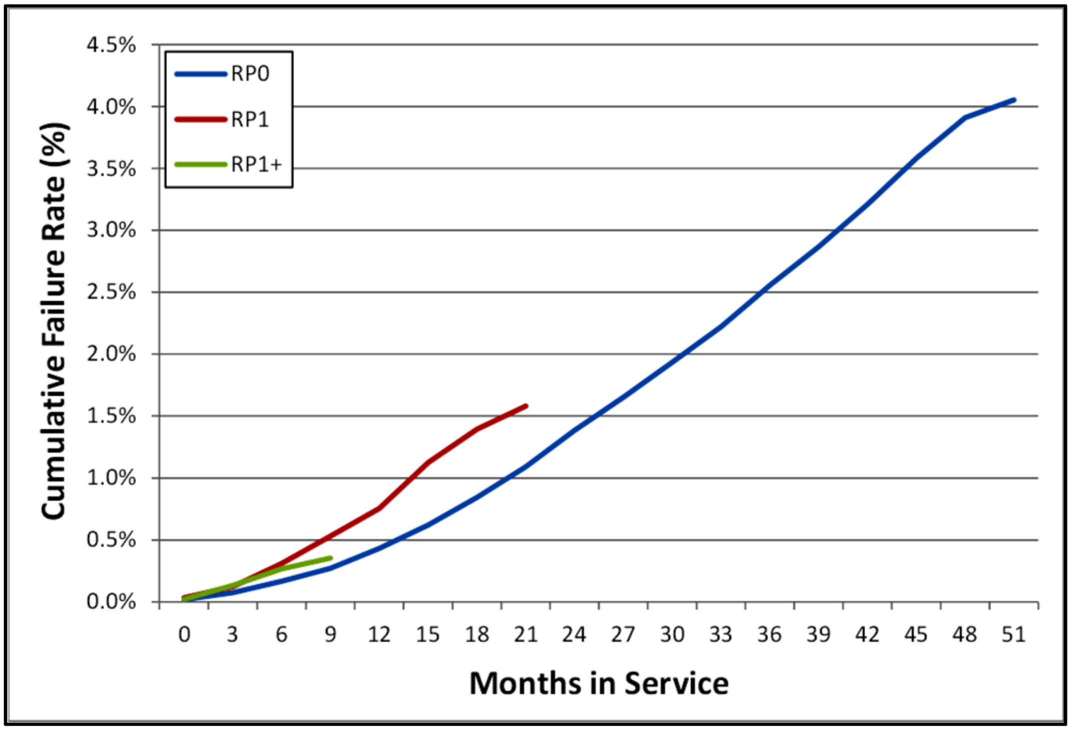

Figure A7. Cumulative Rates by Months in Service and Design Level, HPFP Drivetrain Failures, Excluding Known Misfuels (CP4.1 pumps).

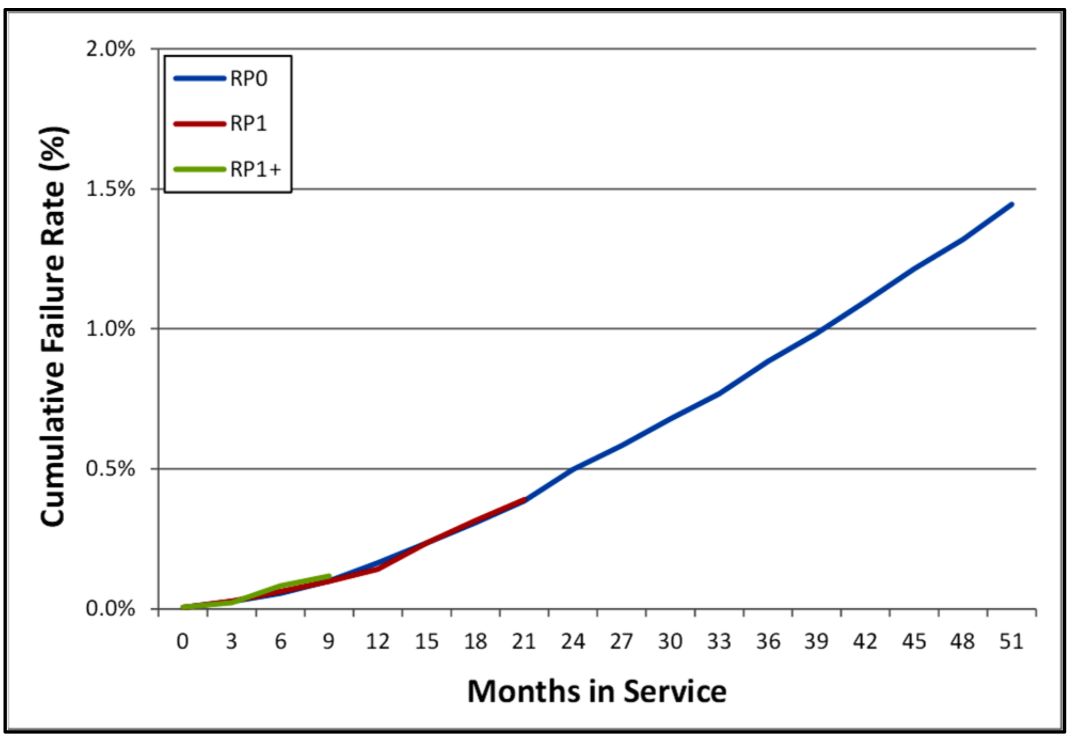

Figure A8. Cumulative Stall Rates by Months in Service and Design Level, HPFP Drivetrain Failures, Excluding Known Misfuels (CP4.1 pumps).

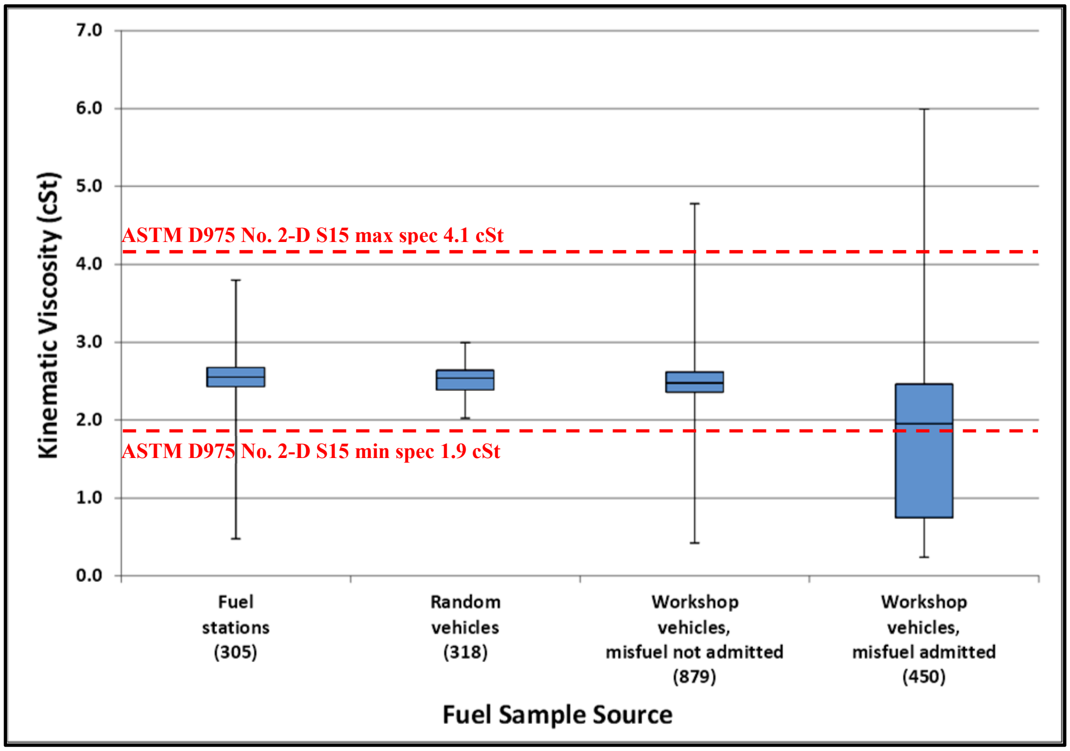

Figure A9. Volkswagen Fuel Viscosity Testing by Sample Group, Workshop Groups <u>Based on Volkswagen Assessment</u> of Complaint & Field Report Records.

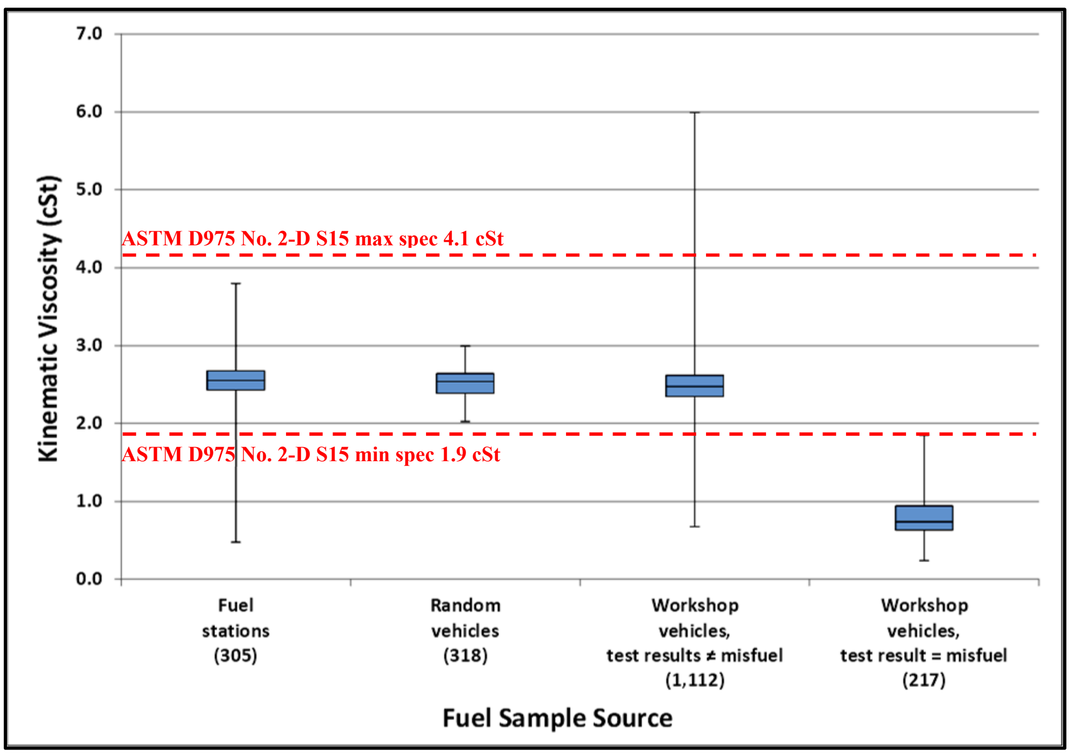

Figure A10. Volkswagen Fuel Viscosity Testing by Sample Group, Workshop Groups <u>Based on Test Results</u> (Misfuel determined by: Kinematic Viscosity < 1.9 cSt AND Flash Point ≤ amb temp).

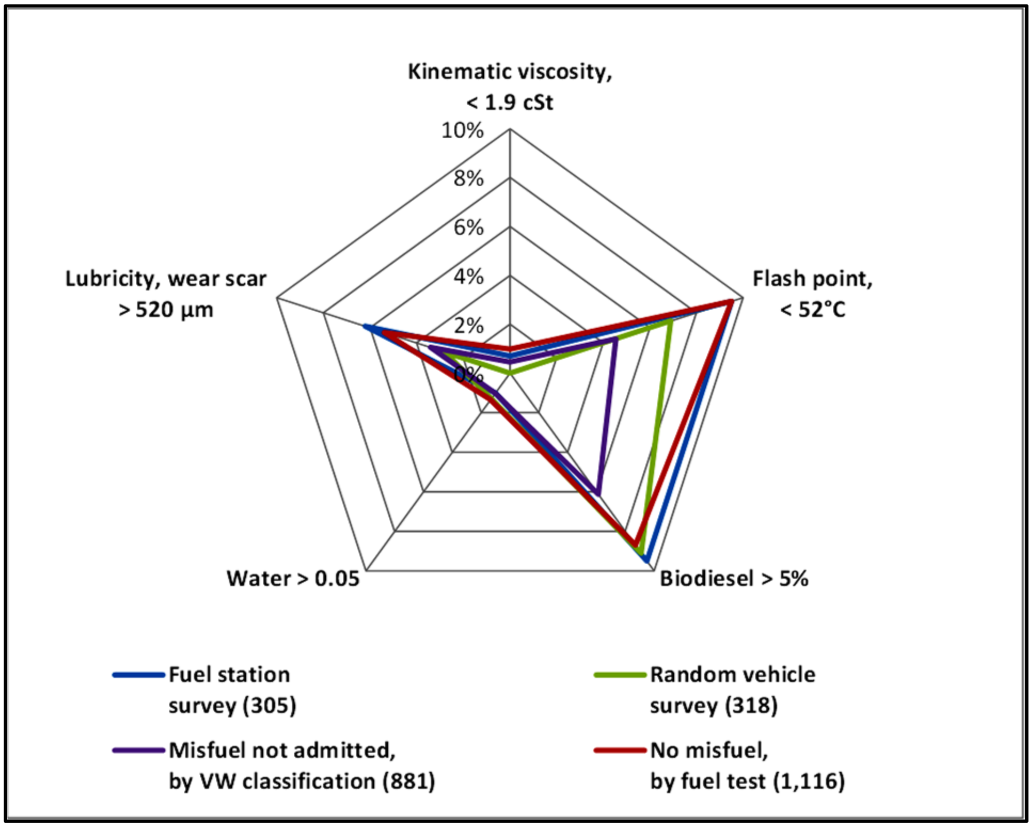

Figure A11. Fuel property out-of-specification results (%), control groups vs "no misfuel" groups.

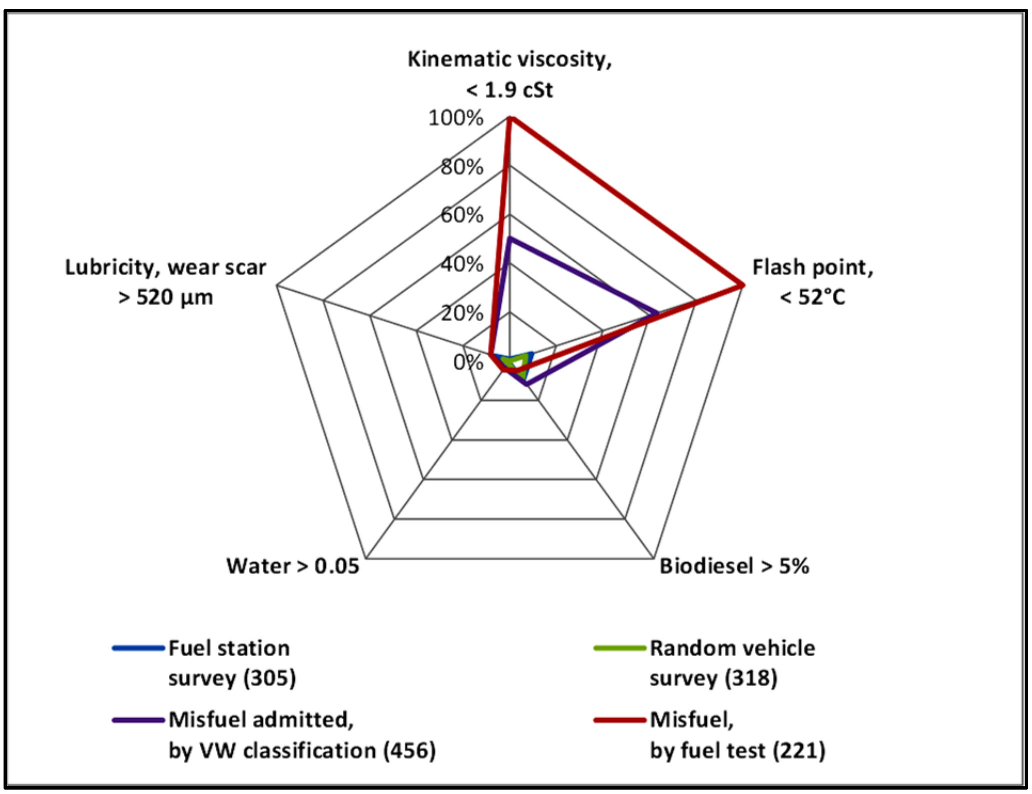

Figure A12. Fuel property out-of-specification results (%), control groups vs misfuel groups.

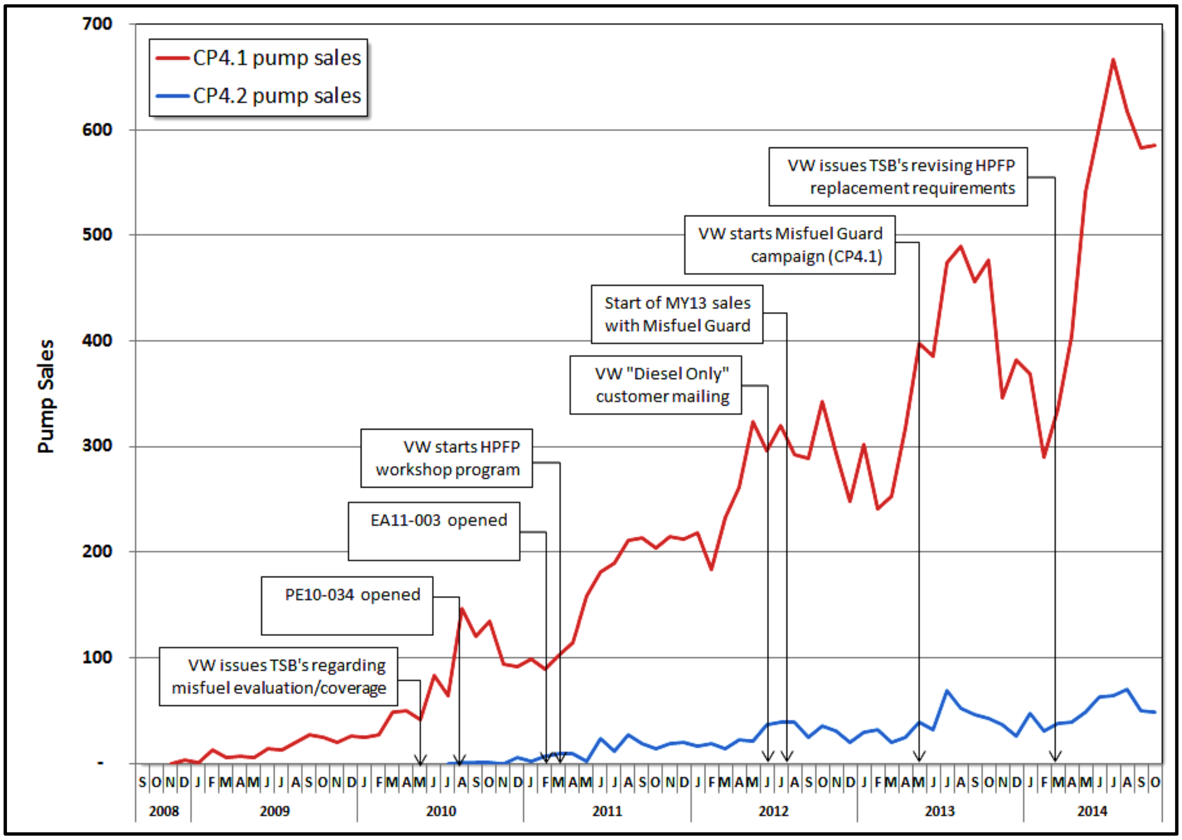

Figure A13. Part Sales Trend by Month Sold.

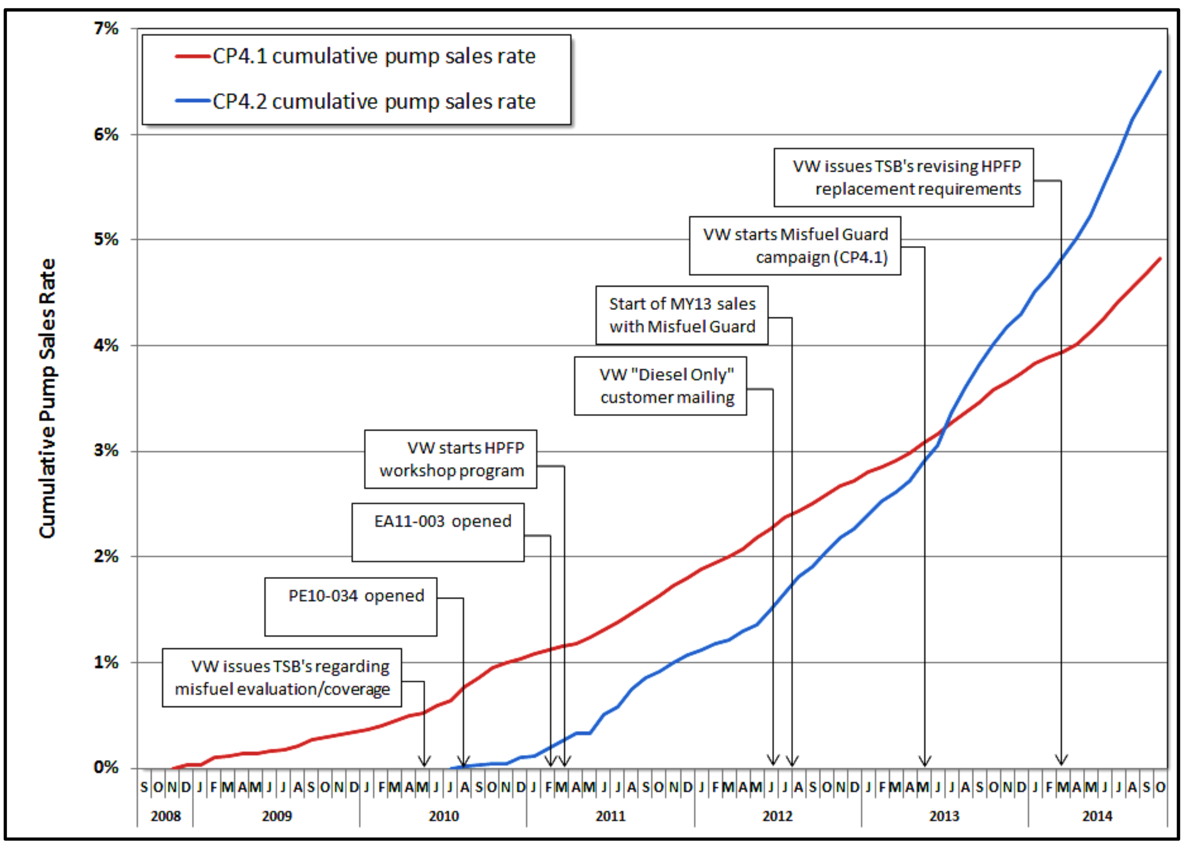

Figure A14. Cumulative Pump Sales Rates by Month
(Cumulative Pump Sales as Percentage of Cumulative Vehicles Sales).

Pump Failure Mode	Pump Design Level			
	RP0	**RP1**	**RP1+/ RP2**	**Total**
Drivetrain failure	91	67	24	182
Other failure	3	4	5	12
NTF/functional	27	37	26	90
Total	121	108	55	284
% Drivetrain	75%	62%	44%	64%
% NTF/functional	22%	34%	47%	32%

Table 11a. Pump Failure Modes by Design Level from Returned Part Analysis, for Incidents VW Did Not Classify as Misfuel from Complaint, Field Report or Warranty Record.

Pump Failure Mode	Pump Design Level			
	RP0	**RP1**	**RP1+/ RP2**	**Total**
Drivetrain failure	9	17	7	33
Other failure	2	2	4	8
NTF/functional	17	84	20	121
Total	28	103	31	162
% Drivetrain	32%	17%	23%	12%
% NTF/functional	61%	82%	65%	75%

Table 11b. Pump Failure Modes by Design Level from Returned Part Analysis, for Incidents VW Classified as Misfuel from Complaint, Field Report or Warranty Record.

Pump Failure Mode	RP0 Design Level			
	Misfuel	No Misfuel	Total	% Misfuel
Drivetrain failure	2	22	24	8%
Other failure	1	0	1	100%
NTF/functional	10	3	13	77%
Total	13	25	38	34%
% Drivetrain	15%	88%	63%	
% NTF/functional	77%	12%	34%	

Table 12a. Pump Failure Mode by Fuel Sample Result, RP0 pumps.

Pump Failure Mode	RP1 Design Level			
	Misfuel	No Misfuel	Total	% Misfuel
Drivetrain failure	1	58	59	2%
Other failure	0	2	2	0%
NTF/functional	34	28	62	55%
Total	35	88	123	28%
% Drivetrain	3%	66%	48%	
% NTF/functional	97%	32%	50%	

Table 12b. Pump Failure Mode by Fuel Sample Result, RP1 Pumps.

Pump Failure Mode	RP1+/RP2 Design Level			
	Misfuel	No Misfuel	Total	% Misfuel
Drivetrain failure	0	16	16	0%
Other failure	1	2	3	33%
NTF/functional	2	20	22	9%
Total	3	38	41	7%
% Drivetrain	0%	39%	39%	
% NTF/functional	67%	53%	54%	

Table 12c. Pump Failure Mode by Fuel Sample Result, RP1+/RP2 Pumps.