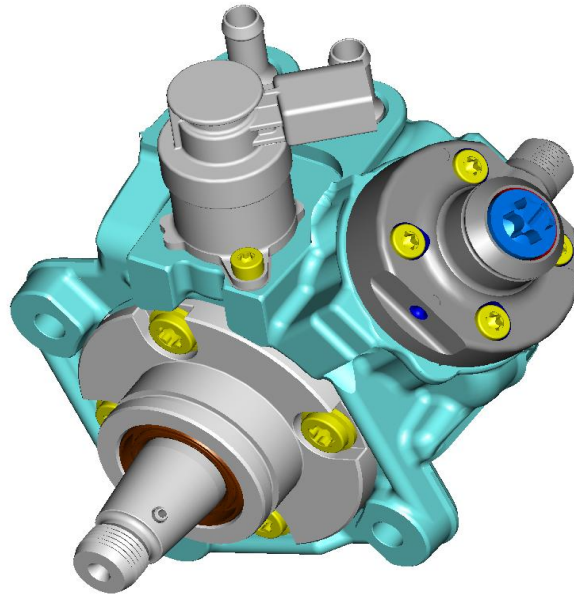




Meeting with NHTSA

May 4, 2011

EA111-003 TDI High Pressure Fuel Pump

INTRODUCTION

- Increasing emission requirements and regulations lead to the development of more sophisticated technology. Distributor pumps injection systems for example – state of the art in the 1990's - would not be able to meet today's emission requirements.
- Evolution of technology is only one aspect – as important is the evolution of operating fluids like engine oil and fuel. Vehicle and fuel form a system.
- Industry standards i.e. for fuel are created to assure that certain minimal specifications are met, but these standards are not always maintained in the field.
- Regular fuel surveys are conducted by the AAM to learn about how specifications are maintained and automotive products are developed accordingly – including certain design margins to deal with off-spec situations.
- However, there is a basic difference between gasoline and diesel engines that cannot be bridged by design margins as essential properties of gasoline and diesel differ.
- For example: Any gasoline engine operated with diesel – or any diesel engine operated with gasoline - will quit running.

INTRODUCTION

- Volkswagen's high pressure fuel pumps are designed to withstand certain off-spec (or low quality fuel) or even certain gasoline contamination, however, if gasoline is mixed into fuel that is already borderline or off-spec, this may exceed the robustness of the design.
- Volkswagen is the only manufacturer who provides high efficient, high performance and „green“ diesel engines in the passenger car segment while competitors now (years later) follow and subsequently introduce the same technology Volkswagen already provides for some years.
- Volkswagen has investigated failures of the high pressure fuel pump and determined that single outside occurrences – outside of the manufacturer's responsibility – caused the failures - – in the majority by misfueling the diesel vehicles with gasoline.
- Especially the random occurrence in a low R/1,000 rate and the fact, that the failure rate of High Pressure Fuel Pumps in Canada – for the same vehicles – is seven times lower shows, that failures are not caused by the design but by market circumstances.
- Volkswagen concludes that no design defect exists in its TDI Clean Diesel vehicles, and that no unreasonable risk to motor vehicle safety exists.

INTRODUCTION

The presentation will

- Provide an overview about the evolution of emission requirements and technology
- Point out that fuels and fuel quality play an important role in the realization of those emission requirements and affect component's durability
- Show, analyse and discuss field data pertaining to high pressure fuel pump related to stalling/loss of power events
- Describe function and operation of the injection system and high pressure fuel pump
- Discuss
 - the impact of gasoline being used in modern diesel engines
 - Analysis of field return parts,
 - failure mechanisms with warning signs and consequences

AGENDA

Based on NHTSA's additional questions, after Volkswagen responded to the PE, Volkswagen has prepared this presentation in the following order

1. Diesel Fuel
2. Field Data Analysis
3. Diesel Fuel Injection System & Components
4. High Pressure Fuel Pumps used in Volkswagen's TDI Clean Diesel vehicles
5. Observations – Conclusions
6. Questions – Discussion

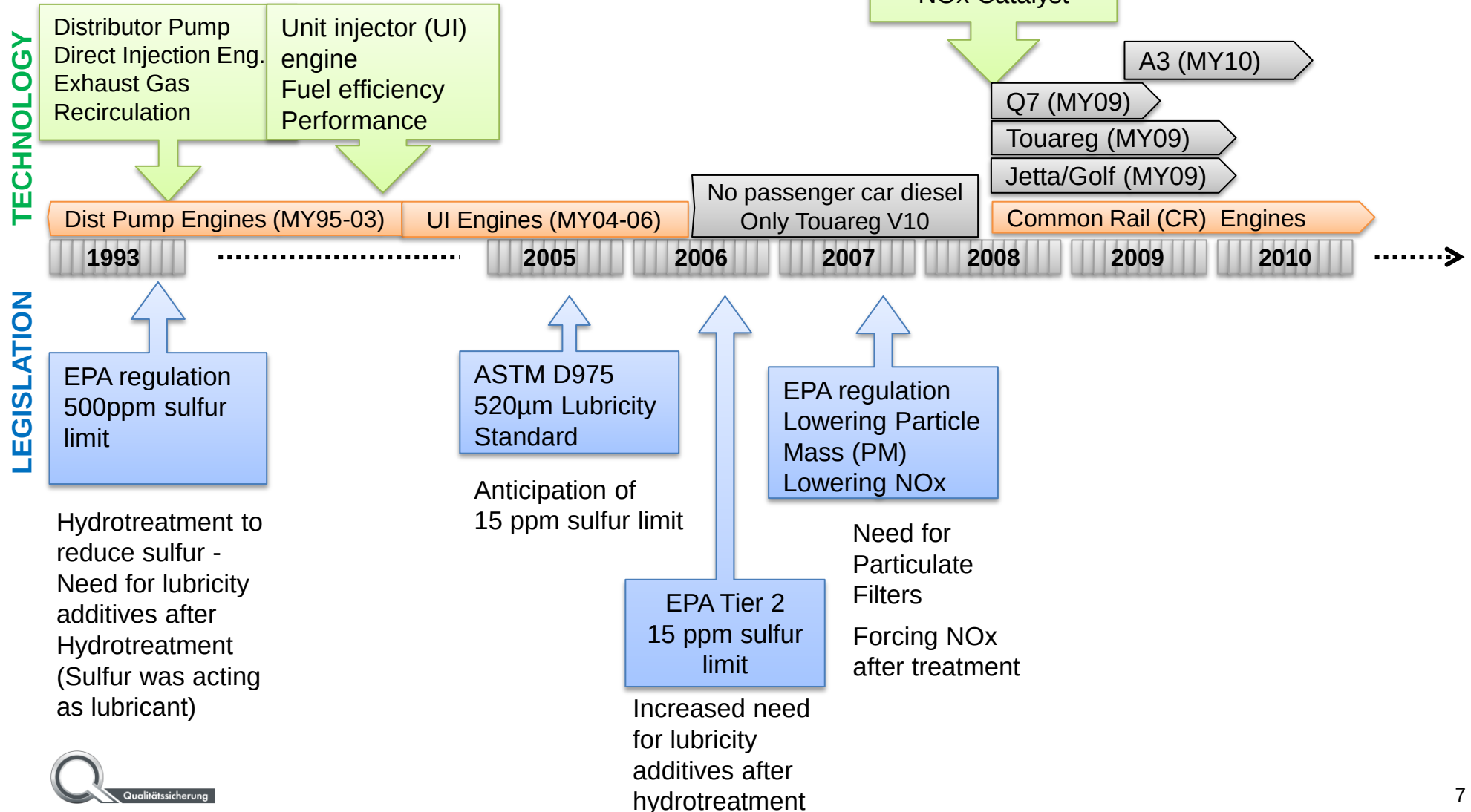
1. Diesel Fuel

Agenda

- a. Historical overview
- b. Properties of interest
- c. Fuel Specifications (ASTM D975 vs. EN 590)
- d. Reference fuels
 - Fuels used for component durability testing
 - Values for fuel properties of interest (e.g., HFRR)
- e. Effects of gasoline contamination on diesel fuel properties
 - Lubricity (HFRR values), viscosity, flash point with 0% , 1%, 5%, 10% gasoline content
- f. Market data regarding diesel fuel quality/variability/contamination?
 - Fuel Quality: Biofuels & Labeling
 - State fuel programs
 - U.S. vs. Europe
- g. Distribution network
 - Actual/potential sources of contamination

1. Diesel Fuel

a. Historical Overview



1. Diesel Fuel

b. Properties of Interest - Introduction

- Historically diesel fuel properties in the U.S. have lower standards
 - Diesel engines are not common in U.S. passenger cars (98% gasoline engines)
 - Petroleum industry focused on maximizing gasoline production
 - “Leftover” crude used for diesel fuel
 - European diesel fuel starts with a higher quality crude stock
 - Diesel in passenger cars common for decades
 - Diesel and gasoline as equitable fuels (50% gasoline / 50% diesel engines)
 - When compared to Europe, US diesel fuel has:
 - Low cetane
 - High natural sulfur
 - Lower lubricity properties
 - Greater ranges of properties related to components
- But the different quality of diesel fuel in the US was taken into account during development of the components of the TDI Clean Diesel vehicles.

1. Diesel Fuel

b. Properties of Interest – Essential Properties

Viscosity The HPFP runs hydrodynamically (roller in roller shoe) , i.e. surfaces are separated by a lubrication film and do not touch each other.

If viscosity is too low, the lubrication film gets too thin to completely separate the surfaces and roller can be „stopped“

Lubricity When the engine/HPFP is off, surfaces are in contact as no lubrication film is present. Until the pump reaches its normal operation range a mixed friction area must be passed. In this mixed friction area lubricity must protect the surfaces from (excess) wear.

Lubricity is also important for proper operation of the rolling contact between roller and camshaft lobe

If lubricity is too low, increased/excess wear can occur, reducing the pump's lifetime.

1. Diesel Fuel

b. Properties of Interest – Additional Properties

- Flashpoint** Indicator for amount easily flammable components (gasoline) with low viscosity/lubricity. No „direct“ influence on durability.
- Distillation** If distillation starts at too low temperatures, diesel may vaporize and gas bubbles can form in the fuel (gas provides no lubrication), this is a theory and not yet proven.

1. Diesel Fuel

b. Properties of Interest – Chemical Components

- Water** Excess amount of water can cause corrosion/rust, disturbing the hydrodynamic properties and lubricity with similar effects as above.
- Biofuel** Does not affect the pump if it is within spec. However, biofuels can aggregate more water than regular diesel and may breed microbes and algae if stored improperly and/or for too long (clogging can occur/residue may be created/roller may stick).
- Ash** Was suspected to cause injection equipment wear if present, however, many samples showed ash content below 0.001% or not measureable, so this was not further pursued
- Sulfur** Sulfur content was limited because of increased emission requirements, reducing the naturally available lubricant „sulfur“ and creating the need for lubricity additives.

Other emission values (NOx, Particle Mass, etc) affect the combustion process and exhaust after treatment (not to be discussed here).

1. Diesel Fuel

c. Fuel Specifications: ASTM D975 – ULSD (No.2–S15) vs. EN 590

Property	ASTM D975 min.	max	EN 590 min.	max.
Cetane Number				
Viscosity				
Lubricity / HFRR				
Copper Corrosion				
Ash				
Water				
Contam./Sediment				
FAME / Biofuel				
Oxidation Stability				
Flash Point				
Sulfur				
Aromaticity				
Carbon Residue				

1. Diesel Fuel

c. Fuel Specifications: ASTM D975 – ULSD (No.2–S15) vs. EN 590

Property	ASTM D975 min.	max	EN 590 min.	max.
Cetane Number	40	-	51	-
Viscosity	1,9 cSt	4,1 cSt	2 cSt	4,5 cSt
Lubricity / HFRR	-	520 µm	-	460 µm
Copper Corrosion	Grade 3		Grade 1	
Ash	-	0,01 %	-	0,01 %
Water	-	500 ppm	-	200 ppm
Contam./Sediment	-		-	24 ppm
FAME / Biofuel	-	5 %	-	7 %
Oxidation Stability	3h (B5), 6h (B6-20)		20 h (B7)	
Flash Point	52°C	-	55°C	-
Sulfur	-	15 ppm	-	10 ppm
Aromaticity	-	35 %	-	8%
Carbon Residue	-	0,35%	-	0,3%

1. Diesel Fuel

c. Fuel Specifications – Summary

US specification allows

- Slightly lower viscosity
- Nearly 30% Lower lubricity* (13% higher HFRR value)
- More than double contamination with water/sediment
- Very low oxidation stability requirements

→ Increased robustness design requirements for US-HPFP

- US specification required a „low-lubricity package“ for the HPFP (provided as of SOP of TDI Clean Diesel vehicles)
- Limitation of the admissible amount of biodiesel to B5 (5% biodiesel)

*(Remark: Lubricity – HFRR value: Surface bound/progressive effect: 113% value → 128% (1.13^2) effect)

1. Diesel Fuel

d. Reference Fuels – Volkswagen & Bosch Testing/Approval Fuels

Property	Unit	Measurement Method	VW		Bosch	
			EN 590 FE DK	US ZL 04/1 DK	RB EN590	GDK570
Cetane Number		DIN 51773	51,00	41....45	51....55,5	52,4
CFPP	°C	EN 116	0....-20	*		
CP	°C	EN 23015	-10,00	*		
Density at 15°C	kg/m³	DIN EN ISO 12 185	820....845	855....865	825....835	805....820
Distillation IBP start	° C	DIN EN ISO 3405		*	176	170....190
Distillation 50% v/v	° C	DIN EN ISO 3405				
Distillation FBP end	° C	DIN EN ISO 3405	max. 360		366	280....300
FAME rate max.	Vol. %	EN 14078			0	0
Flash point	° C	DIN EN ISO 2719	min. 55	*	65	>65....66
Lubricity HFRR	µm	DIN ISO 12156-1	460	570±50	430±30	570±30
NACE rating	A/B/C/D/E	NACE TM0172-2001	A		B	E
Oxidation stability	h	EN ISO 12205	20,00			
Oxidation stability	g/m³					
Sulfur content	mg/kg	DIN EN ISO 20846	max. 10	15±5	max. 10	max. 10
Viscosity dynamic	Ns/m²	DIN EN ISO 3104				
Viscosity kinematic	mm²/s		2....4,5	*	2,5....3,0	1,5....2,5
Water content max.	mg/kg	EN ISO 12937	200			
Copper corrosion		EN ISO2160				
Additives	y/n		yes	no		

* as measured

1. Diesel Fuel

e. Effects of Gasoline Contamination – Volkswagen Laboratory Analysis (after EA resume)

Target: Analyze the effect of gasoline content in diesel fuel on parameters lubricity, viscosity and flash point

Base fuels used:

- | | |
|-----------------|--|
| • US ZL 04/1 DK | VW US „low quality“ reference diesel, used for approval
low lubricity / no lubricity additives |
| • EN590 | Standard Diesel Fuel (from factory fuel station in Germany)
good lubricity / with lubricity additives |

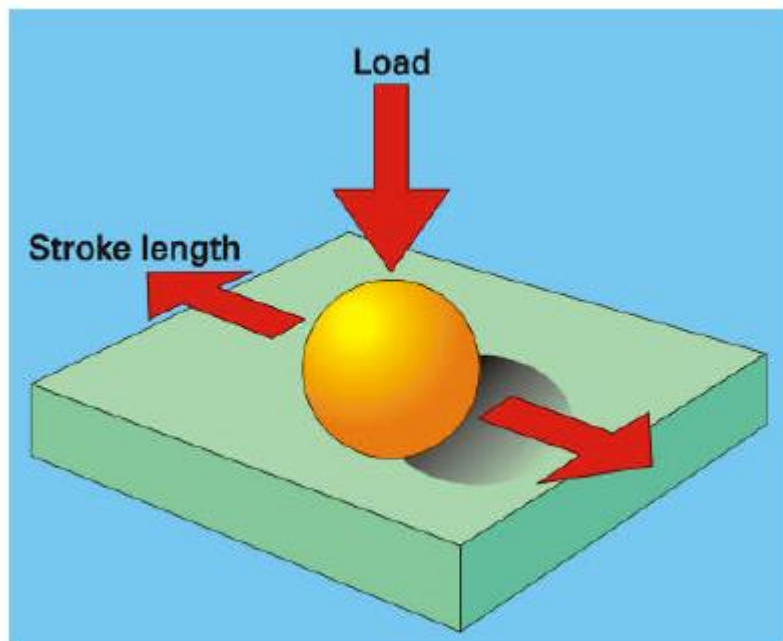
Remark:

- When measured with the standard diesel method, gasoline would evaporate during the test
- Gasoline method uses a closed chamber preventing gasoline from escaping
- Measured values are not directly comparable to the ASTM standard values.
- Reference measurements have been made to correlate diesel and gasoline method

1. Diesel Fuel

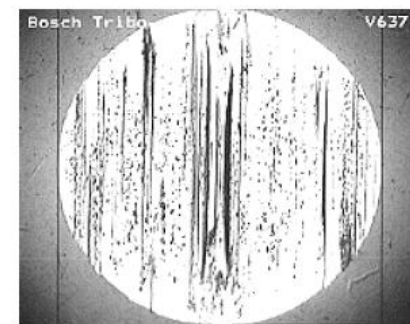
e. Effects of Gasoline Contamination – Lubricity HFRR Measurement Procedure

HFRR = High Frequency Reciprocating Rig



Test conditions:

Applied load	200 g $\pm$ 0.01 g
Stroke length	1 $\pm$ 0.02 mm
Frequency	50 $\pm$ 1 Hz
Test duration	75 $\pm$ 0.1 min
Fluid temperature	60 $\pm$ 2 °C
Fluid volume	2 $\pm$ 0.20 ml
Bath surface	6 $\pm$ 1 cm ²

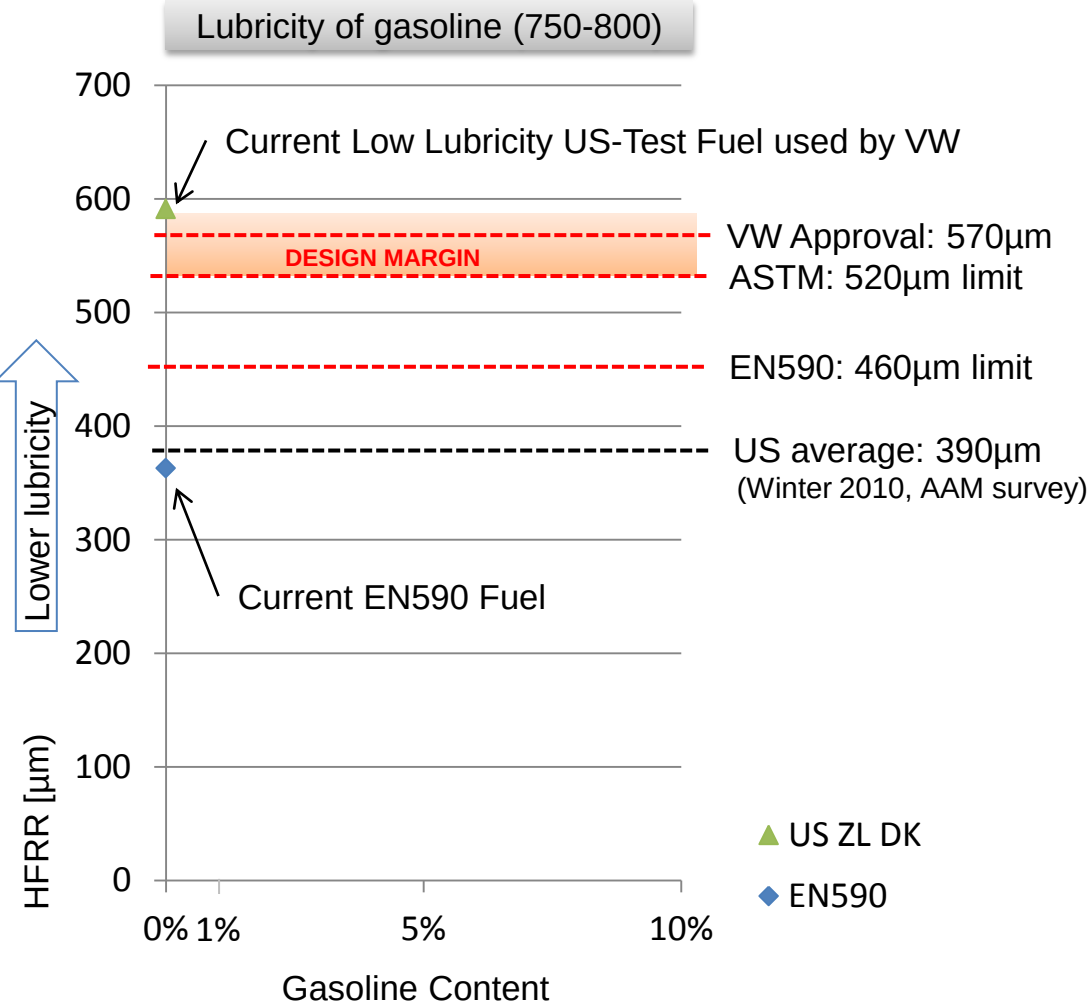


Diesel Method: No chamber, fuel bath open to atmosphere
Gasoline would evaporate (60°C / 140°F)

Gasoline Method: Closed Chamber, gasoline cannot escape
Measurement at 25°C
→ lower temperature provides higher viscosity
→ HFRR values will be below diesel method

1. Diesel Fuel

e. Effects of Gasoline Contamination – Understanding Lubricity Values



Specified Values/ Limits for HFRR-value

US-ASTM: 520µm

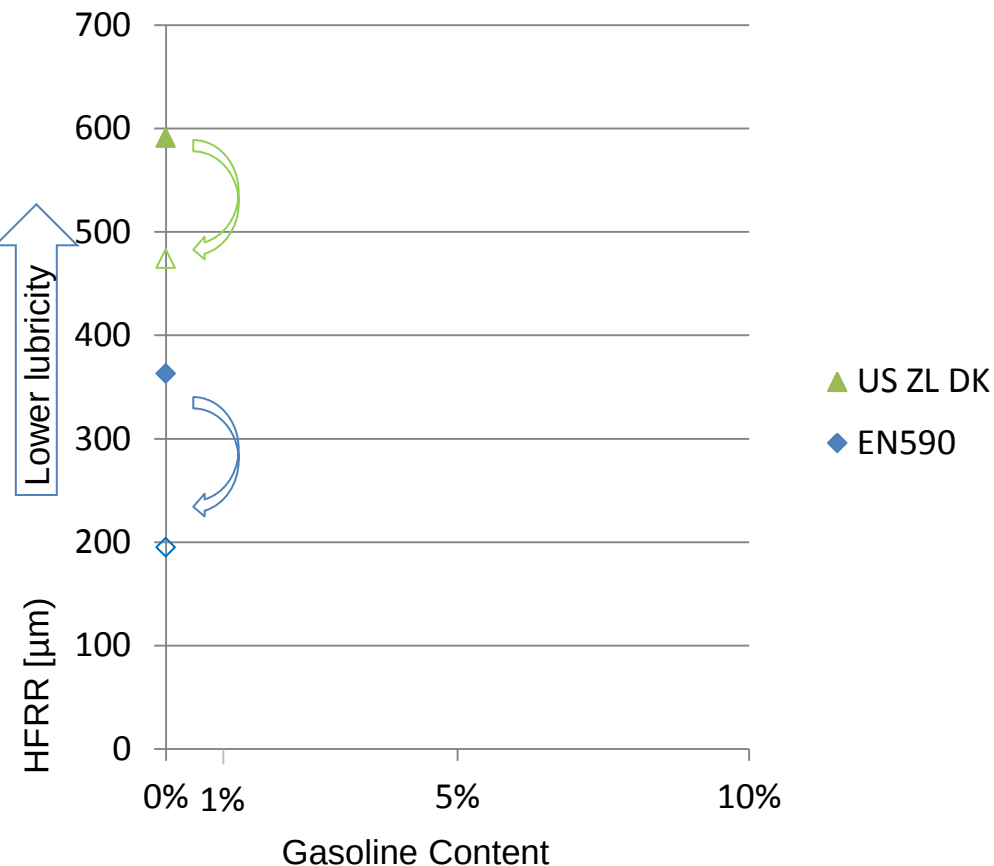
EU590: 460µm

VW Approval with 570µm provides 20%
design margin: $570/520 = 1,096$
[+10% in value → +21% in effect (1,1²)]

- Higher HFRR value means lower lubricity
- 2x HFRR means ¼ of lubricity

1. Diesel Fuel

e. Effects of Gasoline Contamination – Relation of Lubricity Results per Test Method



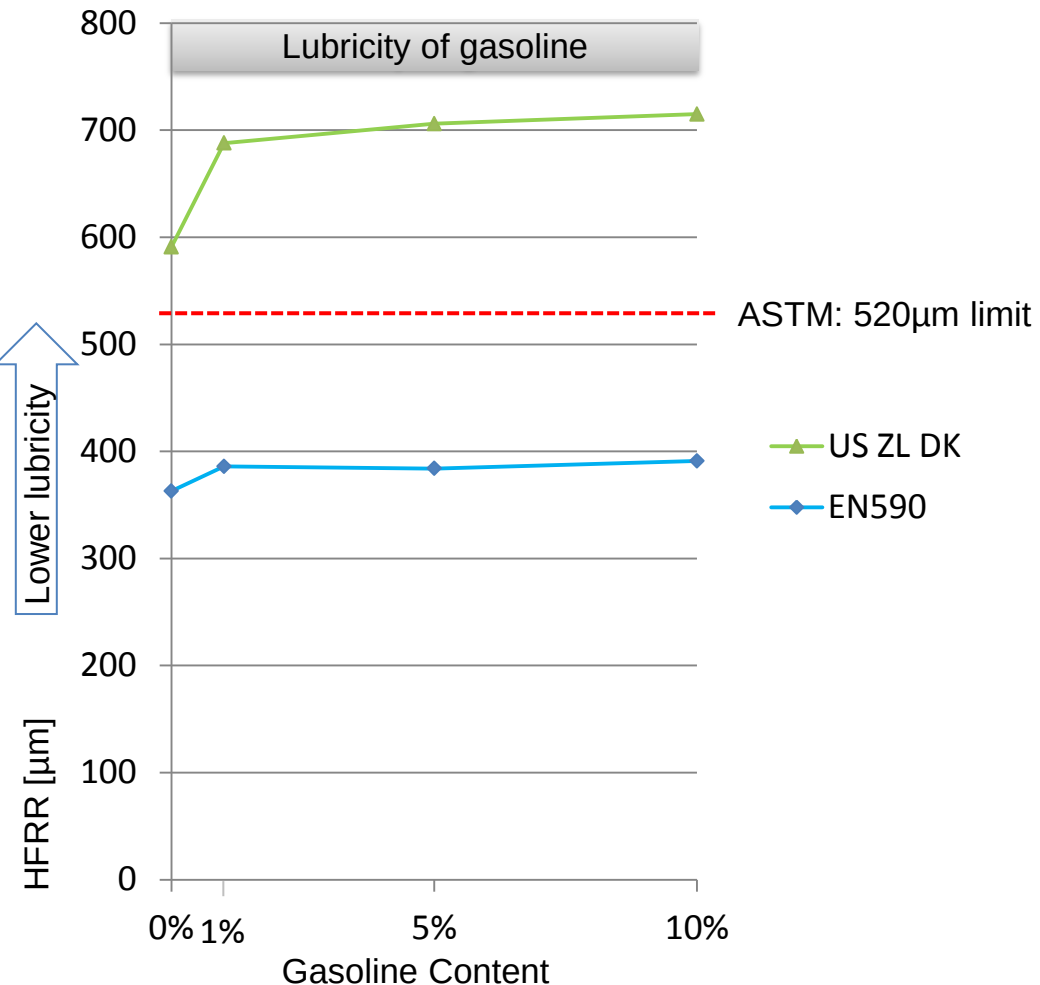
Reference Measurement

- HFRR value will drop when changing from diesel to gasoline method because of lower test temperature (providing greater viscosity)
- Measured HFRR „drop“ will be added to the gasoline method measurements to correct the HFRR values for comparison with the ASTM standard measurement value (correction factor)

Sample	HFRR [μm] Diesel Method	HFRR [μm] Gasoline Method	Correction Factor
A (low lubricity)	591	474	117
B (EN590)	363	195	168

1. Diesel Fuel

e. Effects of Gasoline Contamination – Effect on Lubricity



Findings

Low Lubricity US ZL DK Test Fuel

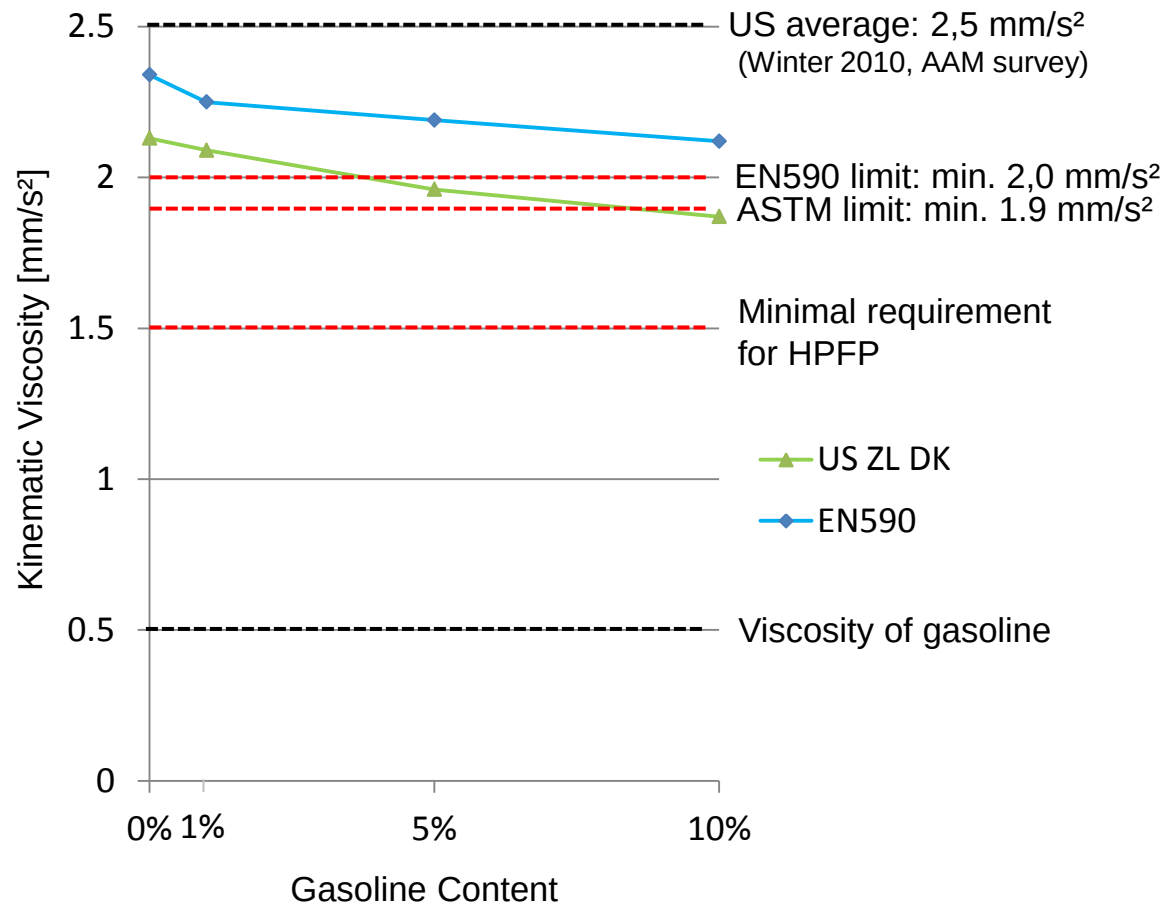
- HFRR increases by 100µm with only 1% gasoline added
- HFRR then increases slowly with more gasoline added

EN590 standard diesel fuel

- HFRR does not actually change;
Only slight increase of about 20-30 µm
– Reason: Lubricity additives compensate the degradation caused by gasoline

1. Diesel Fuel

e. Effects of Gasoline Contamination – Effect on Viscosity

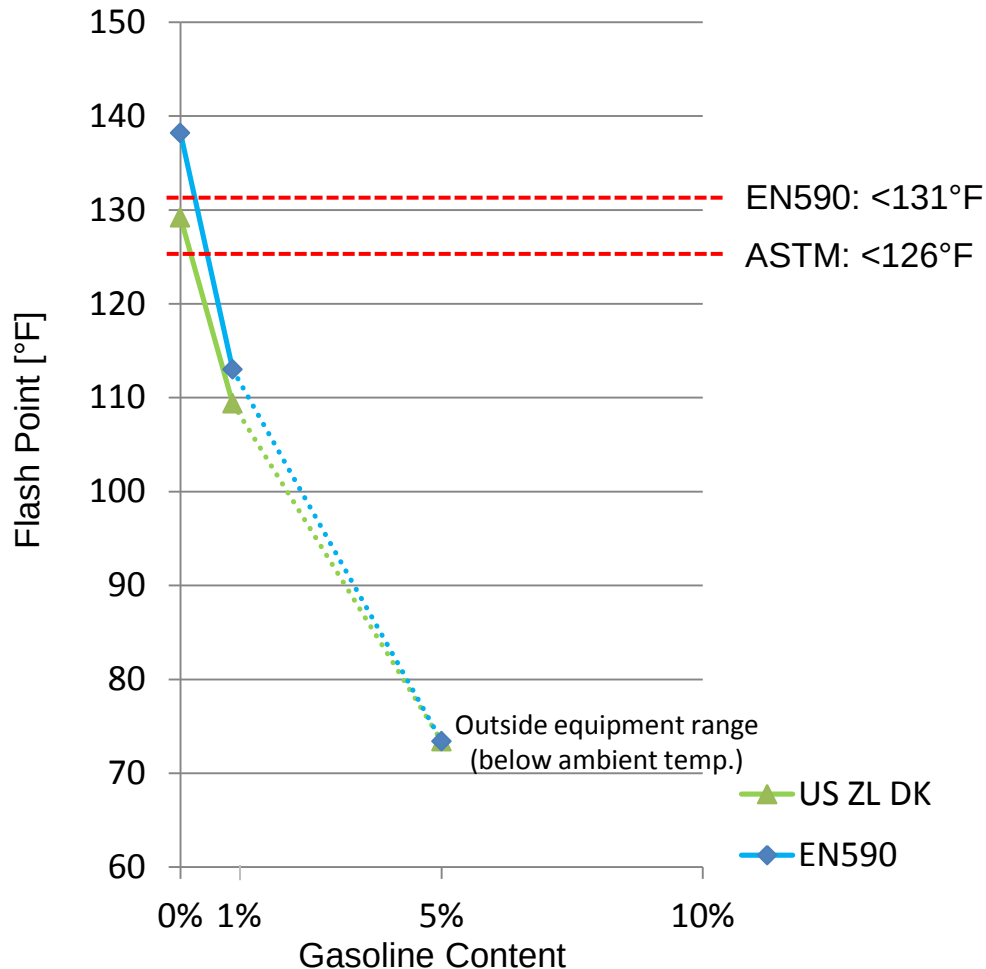


Findings

- Viscosity continuously degrades with increasing gasoline content.
- If base diesel fuel was well within allowed limits, gasoline contamination up to 10% does not create a concern.
- If borderline diesel fuel would be mixed with 10% gasoline minimal required values can be reached.
- Pure gasoline would not provide sufficient viscosity.

1. Diesel Fuel

e. Effects of Gasoline Contamination – Effect on Flashpoint



Findings

- Flashpoint drops immediately out of specification with only 1% of gasoline added
- Gasoline evaporates easier than gas and creates flammable mixture at far lower temp.

→ Flashpoint is a good indicator for gasoline content in diesel fuel

1. Diesel Fuel

e. Effects of Gasoline Contamination – Summary

Lubricity

- Continuously drops when gasoline is added to Diesel fuel with low „base lubricity“
- Small amounts of gasoline will result in a considerable increase of the HFRR-value.
- Lubricity remains rather unchanged for fuel with good „base lubricity“.
- This is caused by additives added to the diesel fuel (to achieve specified lubricity according to ASTM D975 standard).

Viscosity

- Continuously degrades with increasing gasoline content.
- Only diesel fuel matching the lowest allowed viscosity will reach minimal viscosity with 10% and more gasoline added.

Flashpoint

- Flashpoint drops immediately out of spec, even with small amounts of gasoline



- Used as indicator for potential gasoline content

1. Diesel Fuel

f. Market Data – Fuel Quality – Biodiesel/Biofuel Component

- Biofuels in gasoline are restricted by the EPA
- Biofuels are **not restricted** in diesel fuel
 - The result is many different types, levels of diesel biofuels being sold
 - FAME, HVO, BTL, Alcohols, Cooking oils, fats, etc.
 - No controls on quality or quantity

FAME	Fatty Acid Methyl Ester
HVO	Hydrotreated Vegetable Oil
BTL	Biomass to Liquids

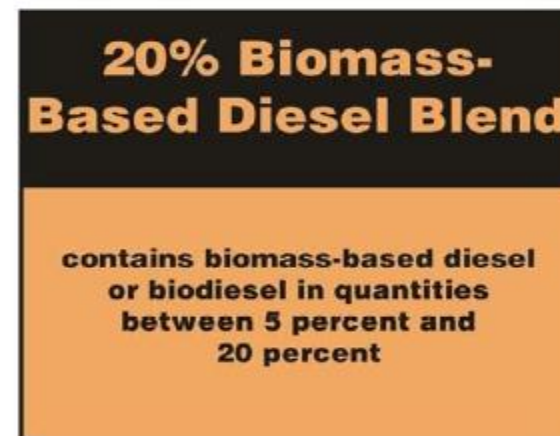
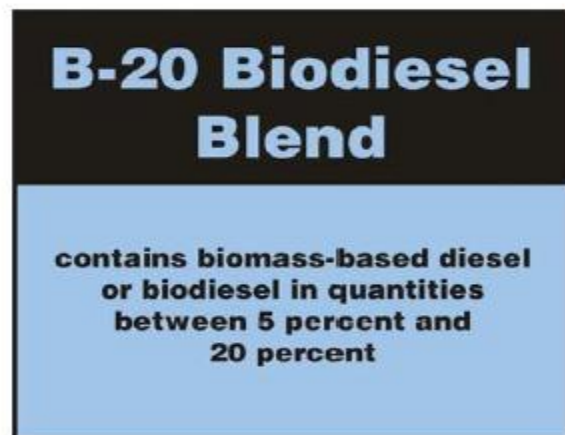
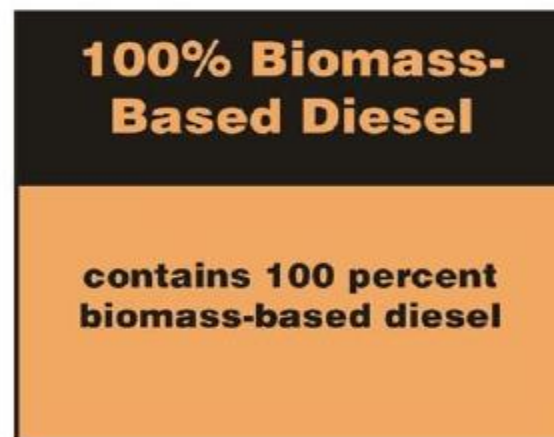
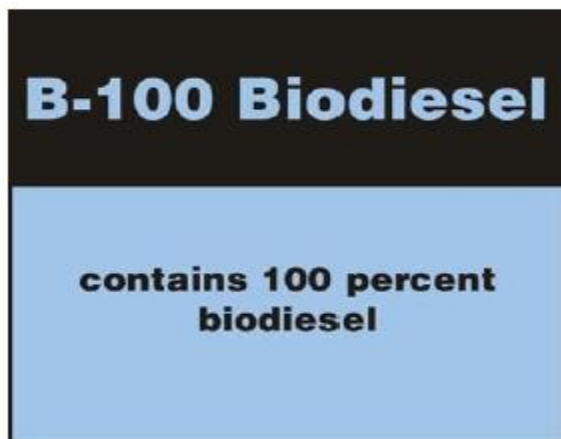
1. Diesel Fuel

f. Market Data – Fuel Quality – Fuel Labeling

- Prior to December 2008, many fuels were not labeled
- FTC (Federal Trade Commission) enacted a biodiesel labeling regulation Dec. 2008
 - B0 – B5: No label required
 - B6 – B20: Label states fuel may contain biodiesel within this range
 - B20+: Label with exact amount must be specified
 - Before label regulation: B11 was sold in Illinois without label

1. Diesel Fuel

f. Market Data regarding Fuel Quality – Fuel Labeling on Pumps – Examples



1. Diesel Fuel

f. Market Data – State Fuel Programs

Volkswagen is currently aware of only two State Fuel Programs:

- B11 encouraged in Illinois due to a tax credit
- B10 coming in Minnesota next year

1. Diesel Fuel

f. Market Data – U.S. vs Europe

U.S. Market

- Alliance of Automobile Manufacturers evaluates U.S. market twice a year
- Survey shows fuel generally according to specification
- Single samples (about 10%) are found to be out of specification

European Market

- In Europe regular surveys – similar to the US survey – are not conducted
- Last EU fuel quality monitoring report (2007 data) was published in 2009
- Generally, compliance with EN590 specification is not an issue in Europe
- 2009 EU report identified deviation from the specification in the R/1000 range
(The report only identifies samples that exceed specification without identifying the parameter or the value)

1. Diesel Fuel

f. Market Data – U.S. vs Europe – US / AAM Alliance Fuel Survey

Example Statistical Analysis of last Winter's Fuel Survey (2010): 141 samples taken

Property	Spec	Average	To Spec	Slightly Outside Spec	Value	Far Outside Spec	Value
Viscosity	1.9-4.1cSt	2.51cSt	140	1	1.68 cSt		
Lubricity	<520µm	386.9µm	129	11	>520 µm <550 µm	1	@619 µm

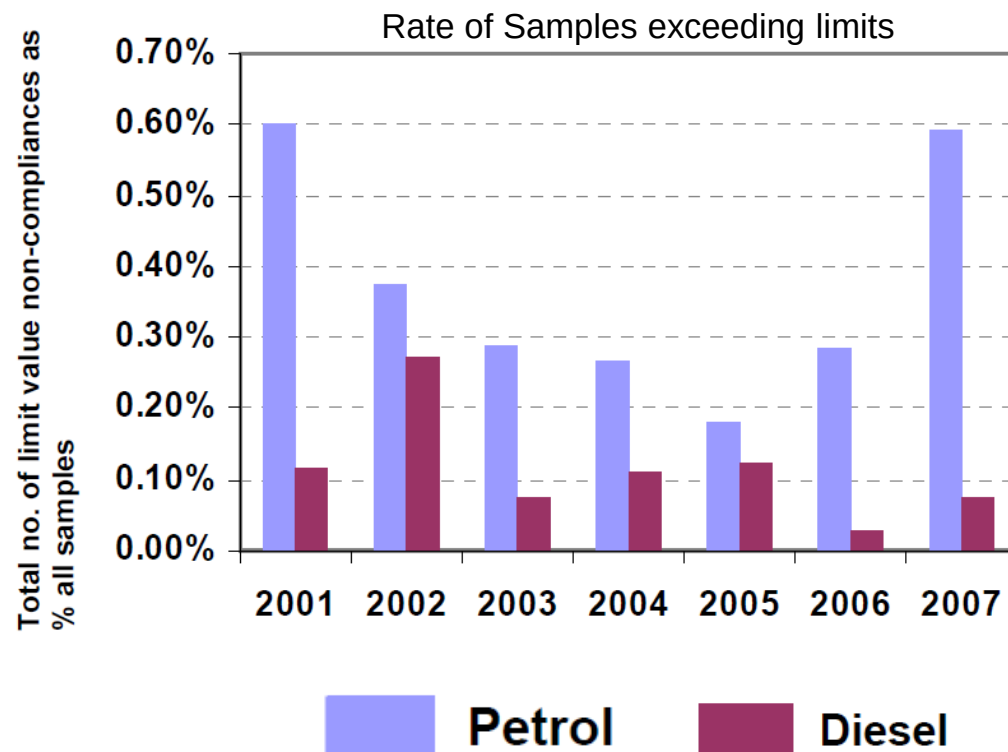
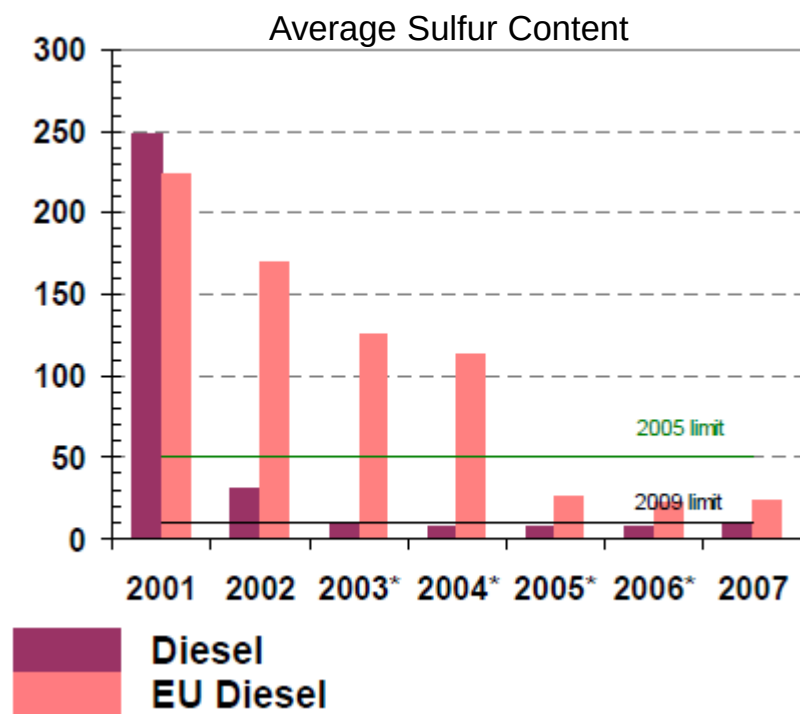
Summary:

- A number of samples (viscosity and lubricity) out of spec, but still covered by the HPFP's design.
- One sample (HFRR of 619µm) is far beyond specification. Appears to have been Jet A1 fuel sold as diesel.

1. Diesel Fuel

f. Market Data – U.S. vs Europe – Examples from EU Fuel Survey

- Parameters analyzed: Cetan Number, Density, Sulfur-Content, T95% (Destillation), Biodiesel content)



1. Diesel Fuel

g. Distribution Network – Actual / Potential Sources of Contamination

Actual Sources of Contamination

- Mistakes when filling gas station earth tanks
- Aging of Biodiesel/Biofuel
 - Algae, mircobes or bacteria growth

Potential Sources of Contamination

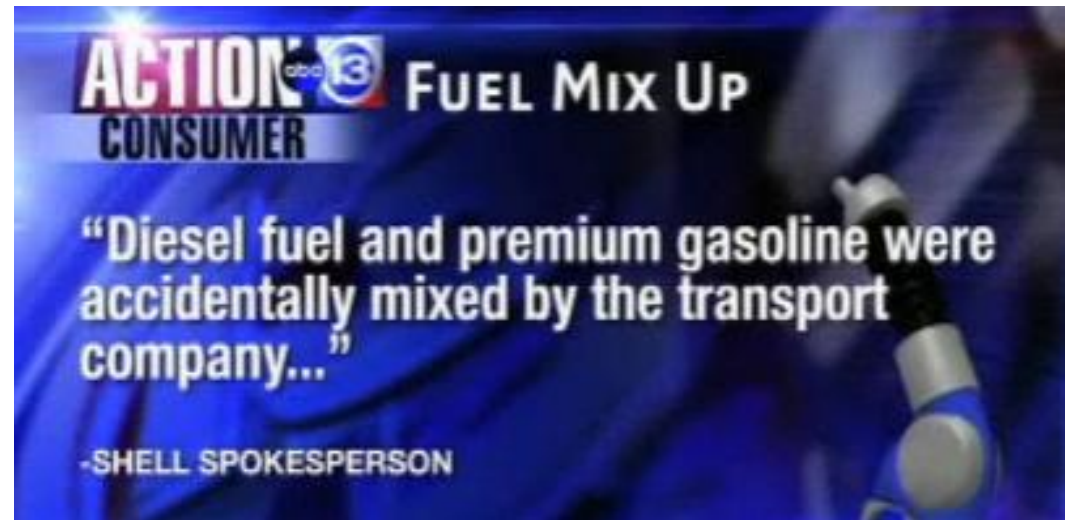
- Fuel Supply Trucks
 - Tank not properly cleaned, remnants from other fuels, water, detergents
- Pipeline Transportation
 - Intermix Phases
 - Pipeline Cleaning
- Confusion at Fuel Station – Fuel Pumps
- Binding Character of Standards
 - U.S. refinery provides ASTM standard fuel, but not thereafter
 - EU guarantees EN590 at the fuel pump nozzle
- Customer low on fuel and no diesel station in range
- Small refineries not producing according to ASTM specification

1. Diesel Fuel

g. Distribution Network – Actual Contamination Sources

- Diesel & gasoline mixed in the fuel station's tanks (here diesel filled into gasoline tank)
 - ABC broadcast from Feb 18, 2011
 - Gas station insurance to cover damages & special Shell telephone hotline for support

→ Fuel hoses from carriers are not „coded“ to prevent mistakes



1. Diesel Fuel

g. Distribution Network – Actual Contamination Sources – Sale of „Contaminated Fuel“

- Newspaper Article about sale of „contaminated“ diesel fuel (contamination is not specified)
- Expensive repairs were caused (\$ 16,000)
- „Several“ violations and penalties mentioned

ORANGE COUNTY - The Texas Commission on Environmental Quality confirms to KFDM News that test results confirm contaminated diesel fuel was sold at a service station in Orange County.

The King family recently bought a \$50,000 Dodge Ram truck. On July 10 they bought diesel at J.R. Conoco on FM 105 near Pine Forest. They say their new truck immediately stopped running and they had to spend \$16,000 on repairs.

...

The owner of the Conoco was notified of several violations and the TCEQ will send him a letter spelling out fines and penalties the owner will face.

1. Diesel Fuel

g. Distribution Network – Actual Contamination Sources - Biofuels

- Biodiesel is an organic fuel that ages and deteriorates over time
- Bacteria, microbes or even algae growth can cause acids, gum, form mats, clog filters, reduce lubricity etc. (Source: <http://www.debugamericalatina.com/bacteria-in-diesel.html>)
- Media broadcast example

Cheri said everything seemed fine until about a month ago when the check engine light kept coming on. So she took the car to the VW dealership again and again and again. Mechanics ran diagnostics and lo-and-behold, the discovered algae growing in her fuel tank. Even worse, it had spread all throughout her car.



Source: <http://www.wcsh6.com/news/watercooler/article/153069/108/Woman-discovers-algae-growing-throughout-her-car?odyssey=mod|newswell|text|FRONTPAGE|p>

1. Diesel Fuel

g. Distribution Network – Potential Contamination Sources – Fuel Carrier Trucks

- Internet posting about fuel carriers transporting gasoline, then diesel without cleaning

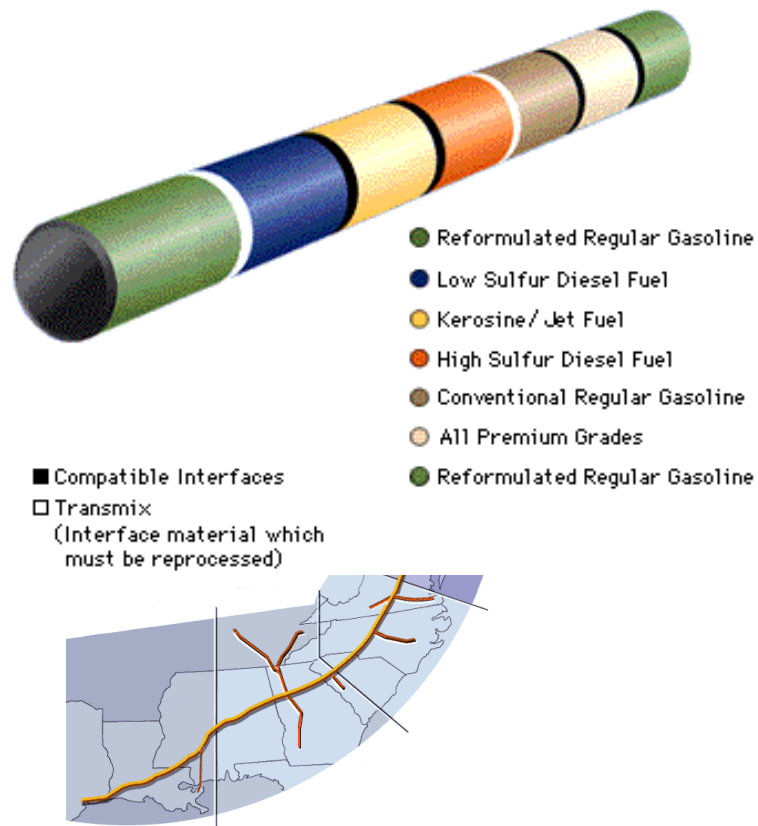
The oil I work with now is ultra-sensitive to contamination (as in down to the parts per BILLION range for surfactants) and 95% of off-spec problems are related to the carrier(s), so I can easily see the situation where a tanker compartment is gasoline one trip and diesel the next. The retailer, of course, is an entire crap shoot. BUT, even if the guy (including US) on the nozzle gets it right, there is no way of knowing if at some time in the life of the tank beneath you, a carrier didn't drop some gasoline in by mistake. I think back to the "gap" time when VW did not certify their diesels in the US market. IIRC, they could not even FIND any LSD at retail distribution points (what would be required to meet emissions at the time). Also, from a friend who sells the stuff by the tanker, a LOT of high sulphur D2 hits the US, and I am still not sure it all gets re-processed before it gets into the distribution system (should be much better now than 5 years ago).

- Appears to be a common procedure (also in Europe)
- Does not create a concern as long as only minimal fuel remains in the carrier prior to re-filling

1. Diesel Fuel

g. Distribution Network – Potential Contamination Sources – Pipeline Transportation

Typical sequence in which products
are batched while in transit on Colonial System



Example „Colonial Pipeline“

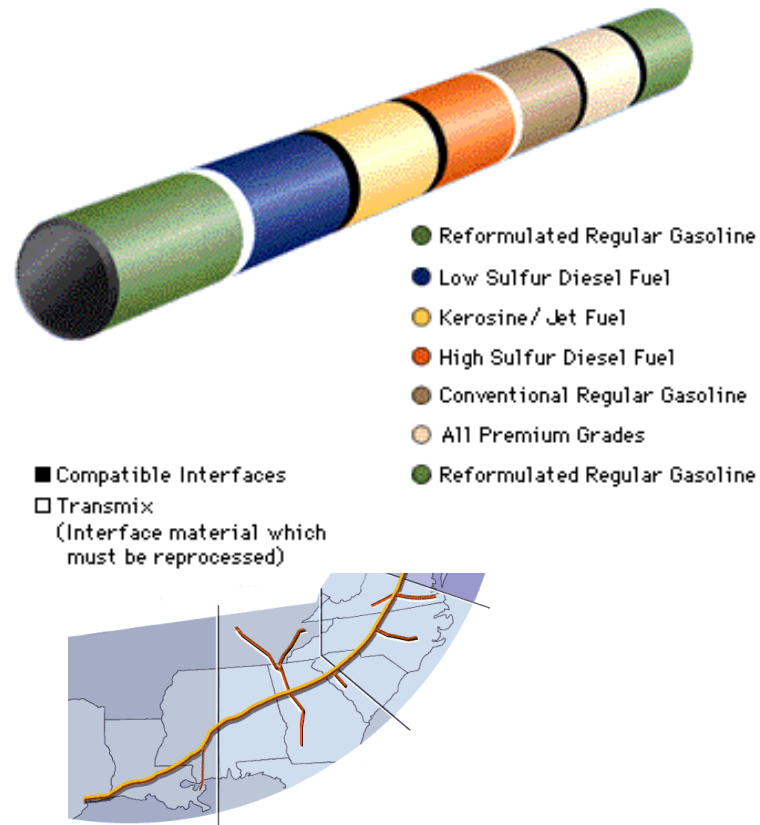
Data from Colonial (http://www.colpipe.com/press_release/pr_109.asp)

- „Colonial“ acts as transportation company and not as reseller
- Different fuels are sent through in grouped batches
- The increased flow rates are achieved by ... use of drag-reducing agents (DRA).
- Every day, Colonial delivers 2.3 million barrels, or about 100 million gallons, of refined petroleum products
- Mainline batches vary from 75,000 to 3,200,000 barrels
- Different product batches are pushed through the system abutting each other. Mechanical separators (pigs) are seldom used. The stream is always in a turbulent flow condition which minimizes mixing. The areas where different products mix are called interfaces

1. Diesel Fuel

g. Distribution Network – Potential Contamination Sources – Pipeline Transportation

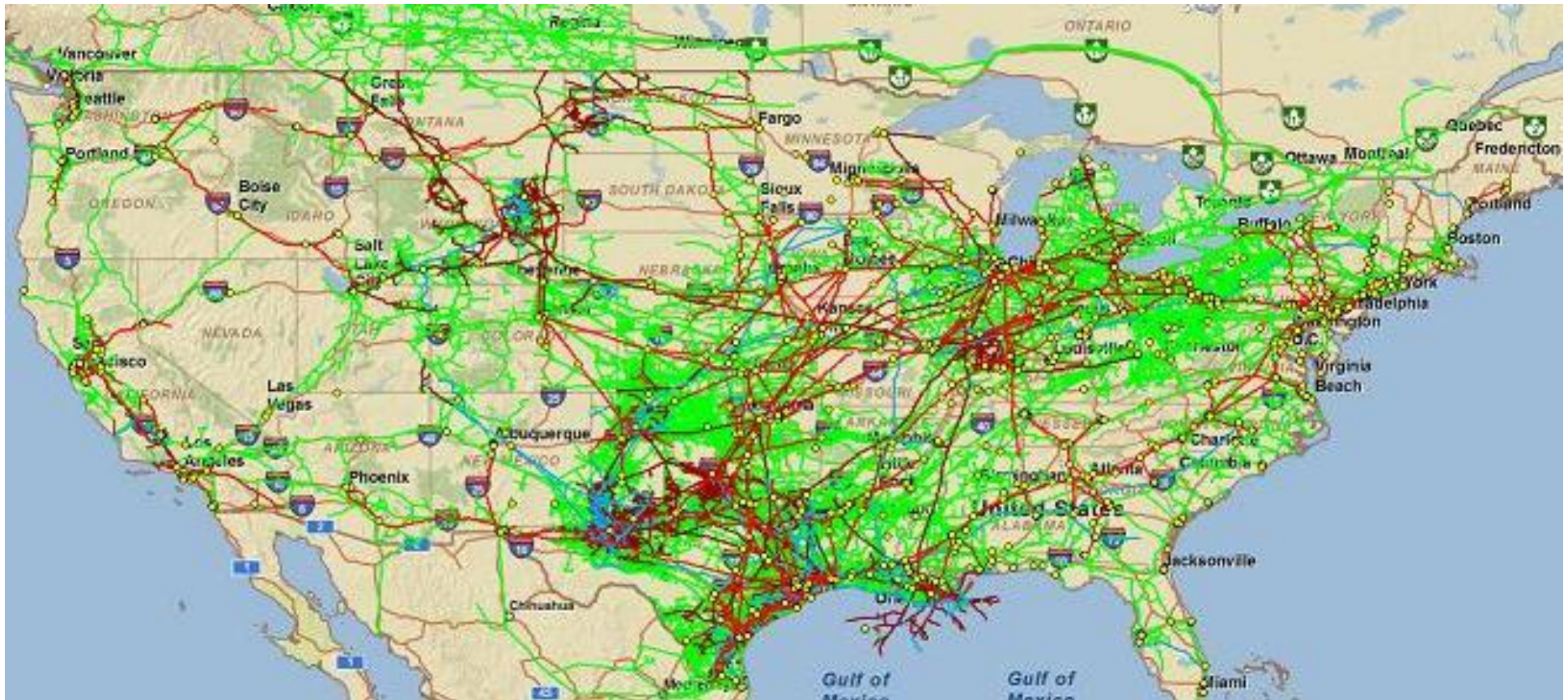
Typical sequence in which products
are batched while in transit on Colonial System



- Batches seldom have a mechanical separation and form an intermix phase inbetween
- Colonial defines a „compatible“ interface for example between Jet Fuel and ULSD, but Jet Fuel would degrade the ULSD's lubricity
- Colonial used „drag reducing agents“ with unknown effects on the diesel fuel and its properties
- Interface would likely not meet the required ASTM Diesel No. 2 ULSD standard
- If „compatible“ interface that does not meet the ASTM D975 standard was used in VW vehicles this could impact the HPFP durability

1. Diesel Fuel

g. Distribution Network – US Pipelines



1. Diesel Fuel

g. Distribution Network – Potential Contamination Sources – Pipeline Transportation

Pipeline Cleaning

- Cleaning devices are used to clean the pipeline walls
 - Mechanically
 - With chemical additives/solvents

→ Remnants could possibly be a source of contamination

1. Diesel Fuel

g. Distribution Network – Potential Contamination Sources – Fuel Pumps

- Standard Fuel Pumps



U.S.



Europe

1. Diesel Fuel

g. Distribution Network – Potential Contamination Sources – Fuel Pumps US

- Other Fuel Pumps / Labels



2. Field Data

Agenda

- a. Market Share & Production Data
- b. Complaints, field reports, warranty claims, VOQs
- c. Analyses
 - Plot counts/rates by incident/production month
 - Mileage distribution
 - Geographic Distribution
 - Market Comparison U.S. vs. Canada
 - Spare Part Sales
- d. Misfuel Incidents
- e. Fuel sampling
 - iPal measurements
 - VW fuel survey

2. Field Data

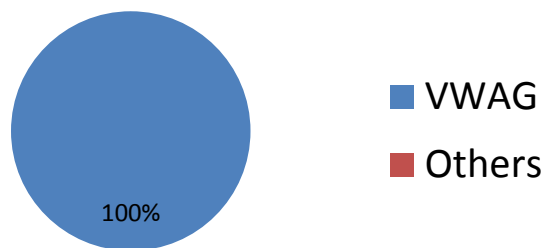
a. Market Share – U.S. Diesel Market (new vehicle sales)

Make & Model	Body	Engine Spec	Fuel System	2009	2010
Audi Q7	SUV	3.0 V6 TDI 225HP 406TQ	Bosch Common Rail Direct Injection	2.094	3.466
Audi A3	Hatchback	2.0 TDI 140HP 236 TQ	Bosch Common Rail Direct Injection	490	3.475
BMW 3-Series	All	3.0L Inline 6 cylinder 265HP 425TQ	Bosch Common Rail Direct Injection	1.656	3.802
BMW X5	SUV			4.582	7.925
Chevrolet Express	Transporter	Duramax 6.6Liter V8 Turbo Diesel 397HP 765 TQ	Bosch Common Rail Direct Injection	544	597
Chevrolet Silverado	Pick-up			31.655	37.013
GMC Savana	Transporter			119	157
GMC Sierra	Pick-up			14.538	16.873
Dodge Ram Pick-Ups	Pick-up	6.7Liter Cummins Turbo Diesel 350HP 650/800 TQ	Bosch Common Rail Direct Injection	33.682	37.934
Dodge Sprinter Series	Transporter			6.798	240
Ford Econoline	Transporter	6.7liter V8 Turbo Diesel 400HP 800 TQ	Bosch Common Rail Direct Injection	2.591	3.507
Ford F-Series	Pick-up			62.044	79.252
Mercedes E-Class	All	3.0 V6 TDI 210HP 400 TQ	Bosch Common Rail Direct Injection	1.212	1.131
Mercedes GL-Class	SUV			2.568	3.501
Mercedes ML Class	SUV			3.034	2.766
Mercedes R-Class	MPV			344	353
Mercedes Sprinter	Transporter	3.0 V6 TDI 188HP 325 TQ	Bosch Common Rail Direct Injection	0	4.808
VW Golf	Hatchback	2.0 TDI 140HP 236 TQ	Bosch Common Rail Direct Injection	613	5.781
VW Jetta	Sedan	2.0 TDI 140HP 236 TQ	Bosch Common Rail Direct Injection	39.537	44.621
VW Touareg	SUV	3.0 V6 TDI 225HP 406TQ**5.0 V10 TDI 309HP 553 TQ	Bosch Common Rail Direct Injection	1.135	1.441
				210.243	260.335

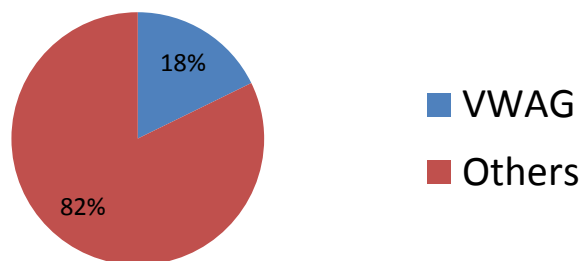
2. Field Data

a. Market Share – Volkswagen / Audi Diesel Vehicles

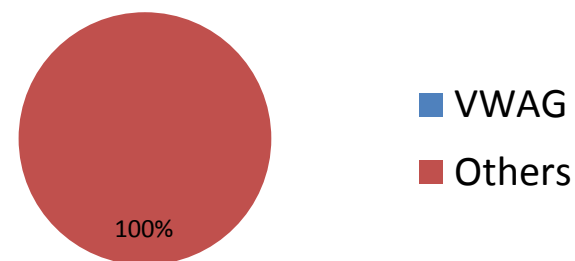
4 Cylinder Passenger Cars



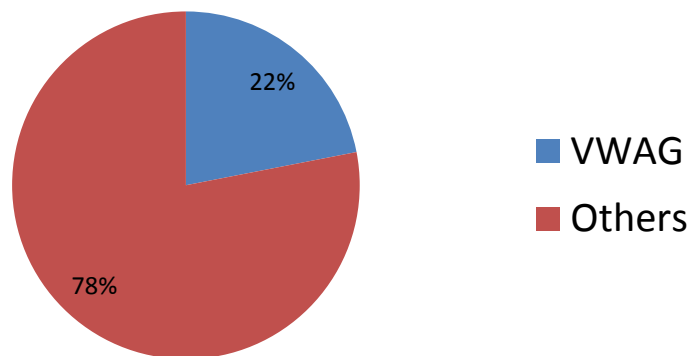
6 Cylinder SUVs & Premium



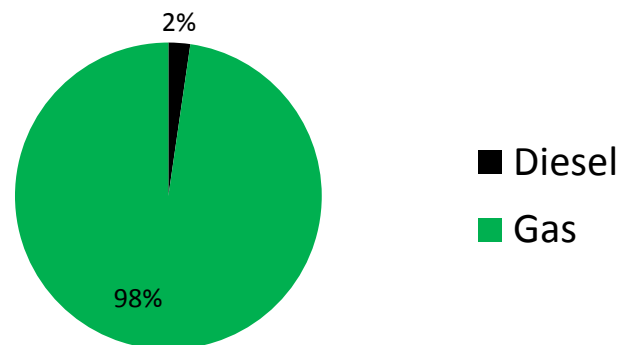
8 Cylinder Pickups & Trucks



Overall



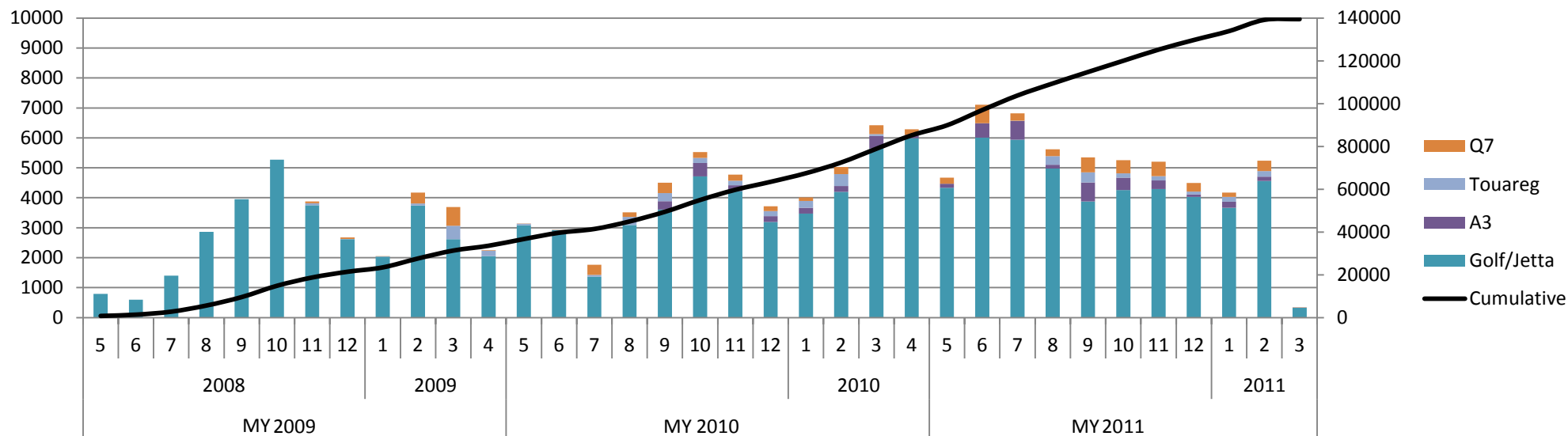
US-Market



Total US annual Sales: approx. 11 Mio. vehicles, 250k Diesel

2. Field Data

a. Production Data (TDI Clean Diesel vehicles)



Model	Production
Golf/Jetta	123.617
Audi A3	5.184
Touareg	3.963
Audi Q7	6.852
TOTAL	139.616

MY2011 still in production

2. Field Data

b. Customer Complaints (CC), Field Reports (FR), Warranty Claims (WC)

- Reports provided with the PE & EA level of the inquiry (multiple counting of incidents)

MY	2009			2010			2011		
Model	CC	WC	FR	CC	WC	FR	CC	WC	FR
Golf/Jetta	39	182	141	15	79	79		1	4
A3					2	5			
Touareg	2	7	7		2	9			
Q7	1	4	4		7	8			

- 444 incidents are subject to this inquiry (PE & EA) when removing the multiple reports (regardless of the reporting system)

2. Field Data

b. FRED vs. ATA/VTA (Field Reporting Entry Database vs. Audi/Volkswagen Technical Assistance)

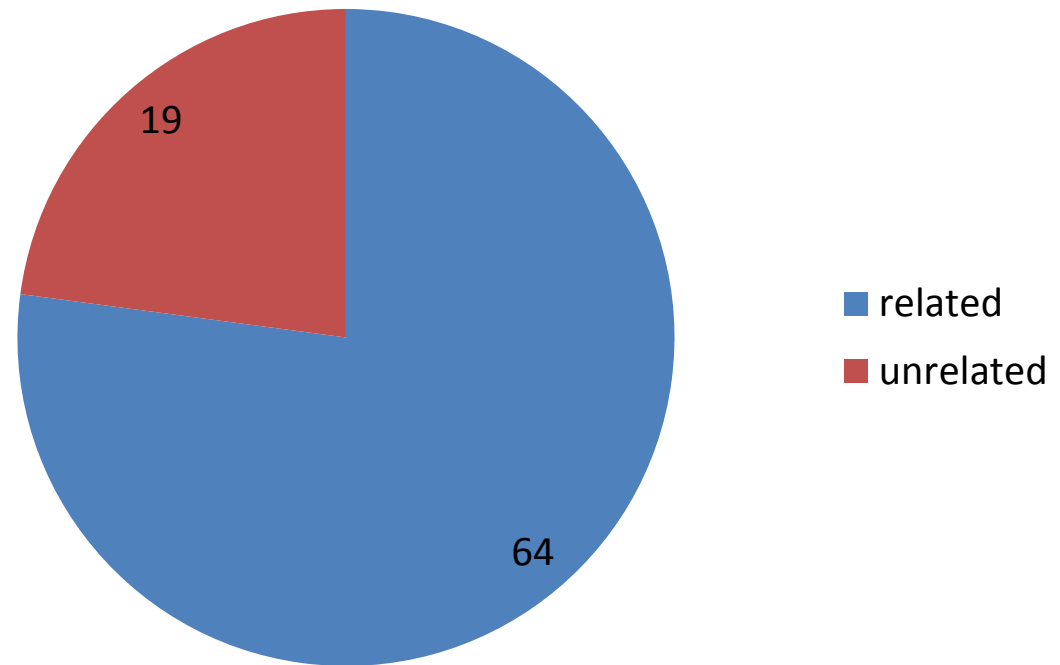
Why some VTA's referenced in other documents are not among field reports submitted

- FRED - Volkswagen / Audi corporate standard field reporting system (employee only)
- ATA/VTA - Record of contact initiated by dealer technician; primary purpose is to assist with repair information or provide guidance relating to a repair procedure
- Warranty - Record a warranty repair on a vehicle
- LISTEN - Record of a customer concern and steps taken towards resolution
- Information reviewed for inquiries are:
 - Obtained directly from the source system, retrieved based on inquiry criteria
 - Source system records are read manually and categorized based on the information contained within the document („4-corners“ review)
 - Systems are not interdependent – record information in one system may not contain identical record information in another system

2. Field Data

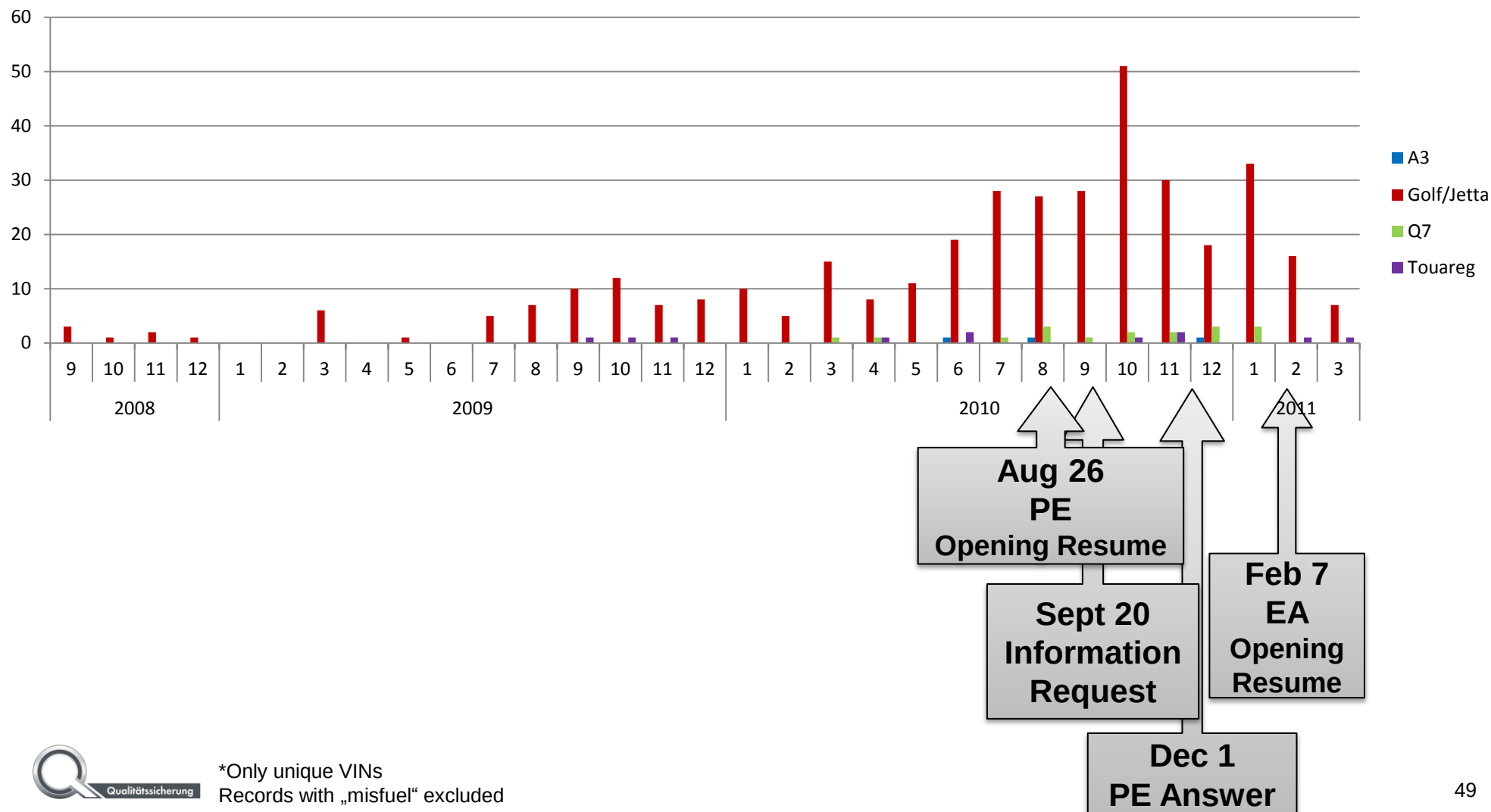
b. VOQs – Overall Evaluation

- NHTSA has provided a total of 83 VOQs
- About $\frac{1}{4}$ appear to be unrelated to the alleged defect or the fuel system (shifting issues, no diesel vehicles, turbo lag)



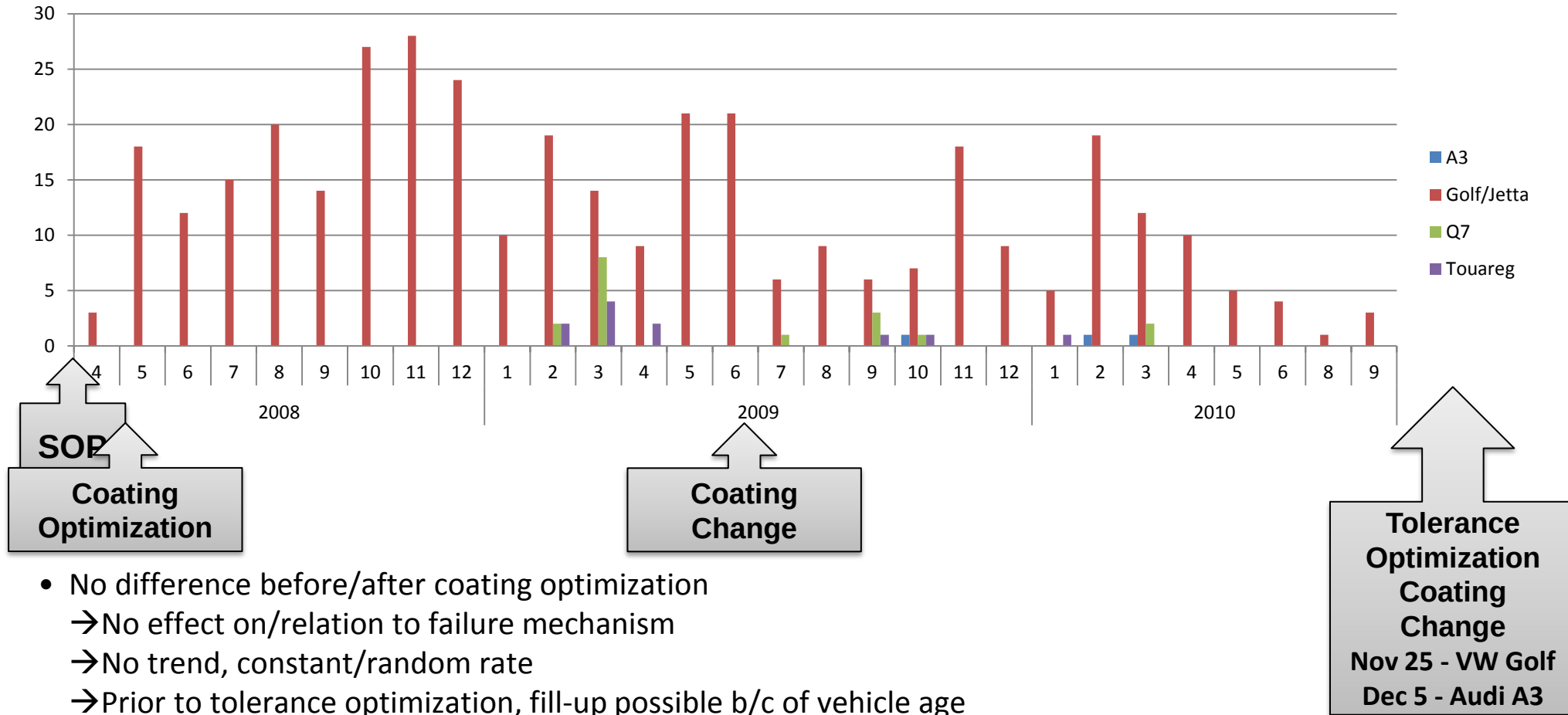
2. Field Data

c. Analyses – Plots by Incident Month – Incidents from PE&EA Records



2. Field Data

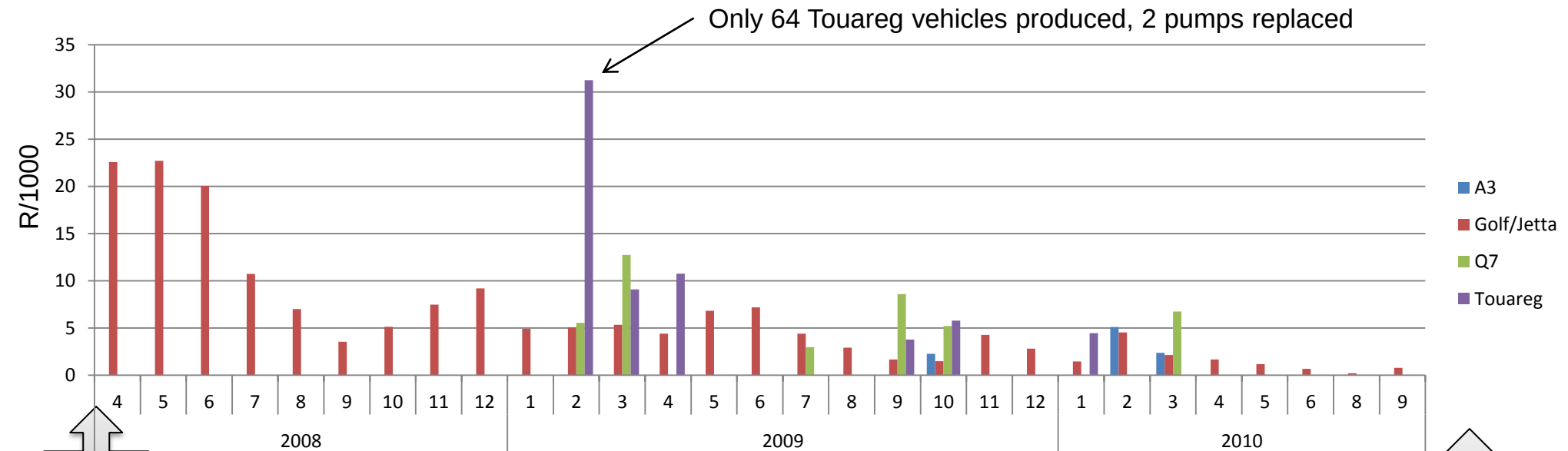
c. Analyses – Plots by Production Month (Counts) – Design History Overlay



- No difference before/after coating optimization
 - No effect on/relation to failure mechanism
 - No trend, constant/random rate
 - Prior to tolerance optimization, fill-up possible b/c of vehicle age

2. Field Data

c. Analyses – Plots by Production Month (Rates) – Design History Overlay



SOP
Coating
Optimization

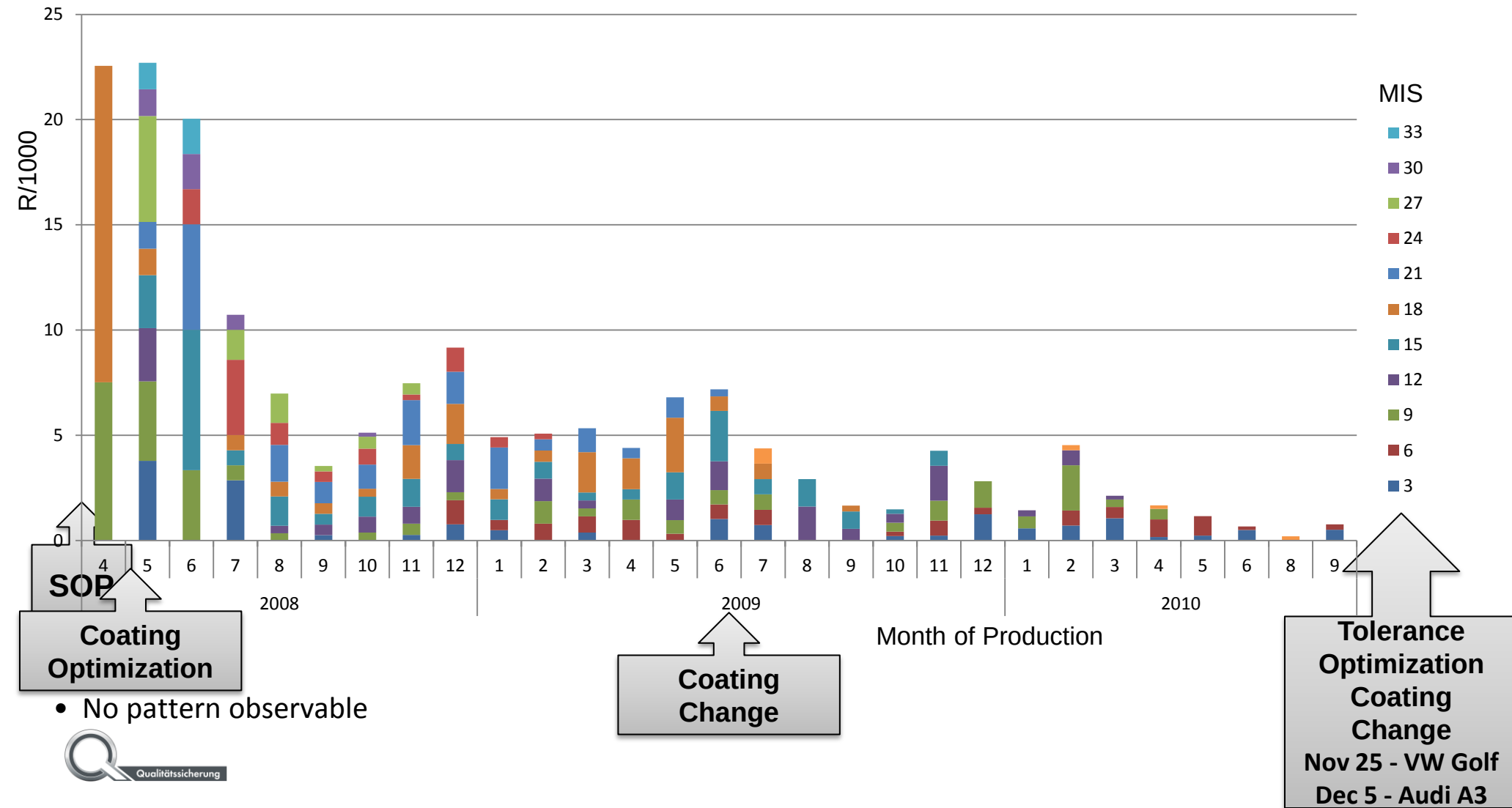
Coating
Change

Tolerance
Optimization
Coating
Change
Nov 25 - VW Golf
Dec 5 - Audi A3

- No difference before/after coating optimization
 - No effect on/relation to failure mechanism
 - No trend, constant/random rate (fill-up effect for younger vehicles)

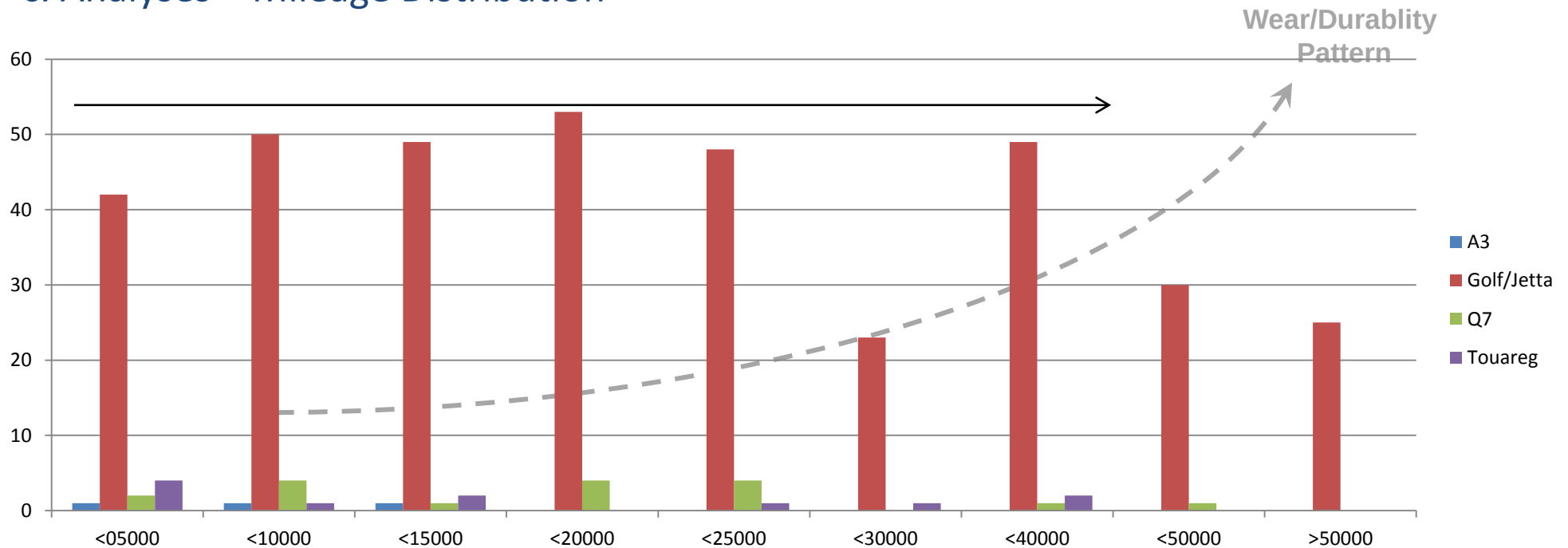
2. Field Data

c. Analyses – Plots by Production Month (Rates) – Stacked Bar Charts by MIS



2. Field Data

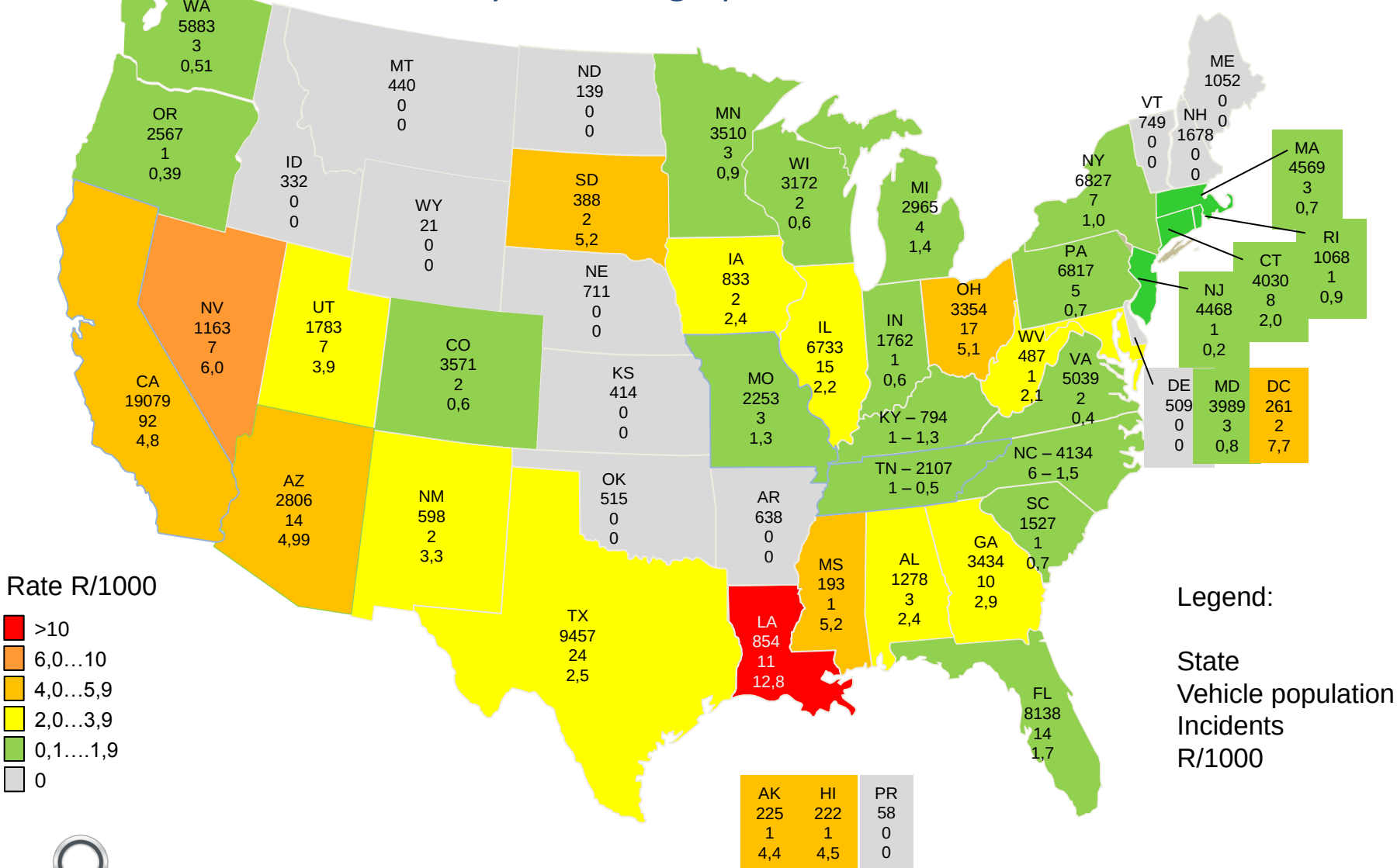
c. Analyses – Mileage Distribution



- Apparently constant rate (random)
- No progression with mileage (no aging/wear/durability effect)
- Wear/Durability Pattern would be increasing with mileage – in grey (for reference) – not observed here

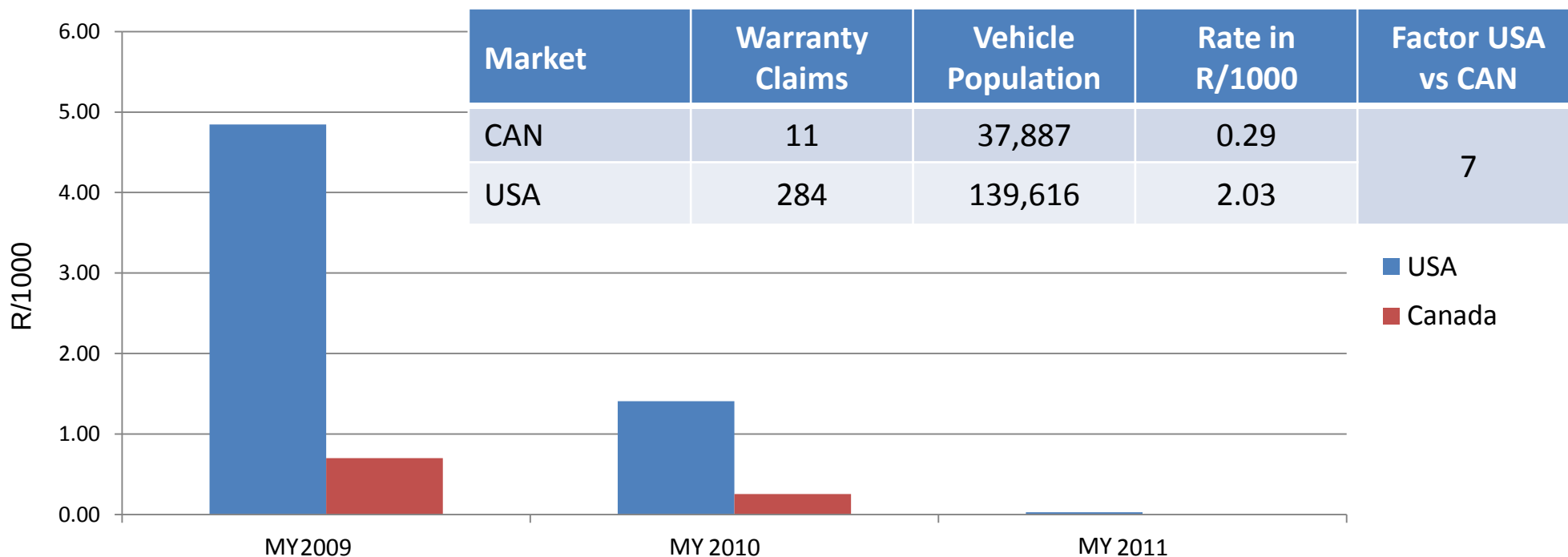
2. Field Data

c. Analyses – Geographic Distribution



2. Field Data

c. Analyses – Market Comparison* - Warranty Rate Canada vs. United States

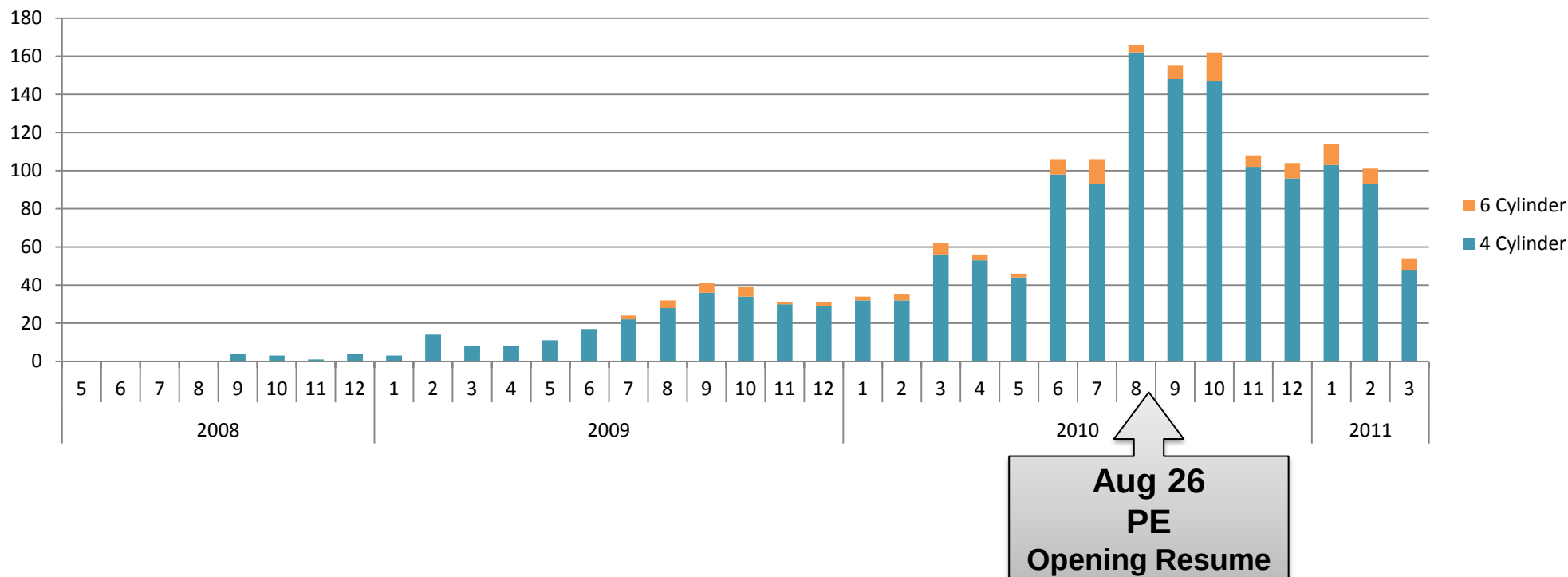


- Same fuel standard, same fuel supply
- Same vehicles (model, engine, injection system, emission standard)
- Warranty Rate in USA 7 times higher than in Canada

* same screening method, same criteria used

2. Field Data

c. Analyses – Spare Part Sales



- Part sales do not record in which vehicle the individual pump went
 - 4 cylinders: Audi A3, Golf & Jetta (1,410 parts – 128,801 vehicles – approx. 1,1%)
 - 6 cylinders: Audi Q7 & Touareg (104 parts – 10,815 vehicles – approx. 1,0%)

2. Field Data

d. Misfuel Incidents / Records Identified

- All incidents where misfuel, fuel contamination or other similar comments were identified have been assembled in a separate file.
- A similar table has also been provided in the PE response
- This table has been updated and analyzed in regard to the contamination source
- A total of **300** incidents have been identified during PE & EA

Definition:

Misfuel – Contamination with Gasoline

Bad Fuel – Other Contamination (off-road diesel, biodiesel, water, etc)

2. Field Data

d. Misfuel Incidents - Comments

- Examples for Claim Comments

CUSTOMER STATES THERE WAS GASOLINE ADDED TO THE DIESEL.

3VWPL8AJ8AM [REDACTED]

TOOK FUEL SAMPLE. FUEL IS RED.

3VWTL7AJ3AM [REDACTED]

VERIFIED WITH THE CUSTOMER THAT THE GASSTATION FILLED IT WITH GAS AND SHE DROVE IT TILL IT STALLED

3VWRL7AJ2AM [REDACTED]

FUNKY SMELL TO FUEL. LIKE KEROSENE .

3VWTL71K09M [REDACTED]

THE LOT GUY PUT FIVE GALLONS OF GAS IN THE TANK

3VWRL7AJ8AM [REDACTED]

CUSTOMER PUT E85 IN TANK INSTEAD OF DIESEL.

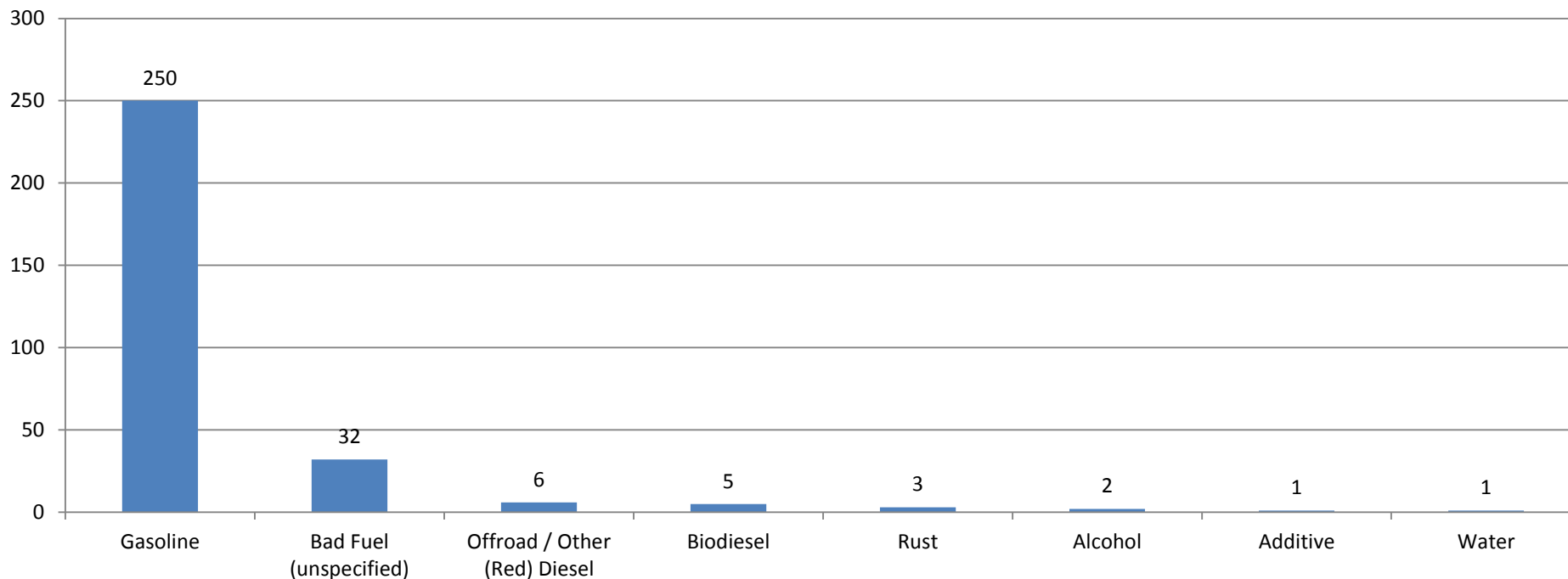
3VWRL7AJ0AM [REDACTED]

CUSTOMER STATES, VEHICLE FILLED UP WITH GASOLINE, (TDI CR), DROVE VEHICLE TILL IT DIED, CRANKED VEHICLE FOR A LONG TIME, NO START POSSIBLE, SYSTEM FILLED COMPLETE WITH GASOLINE,

3VWPL7AJ6BM [REDACTED]

2. Field Data

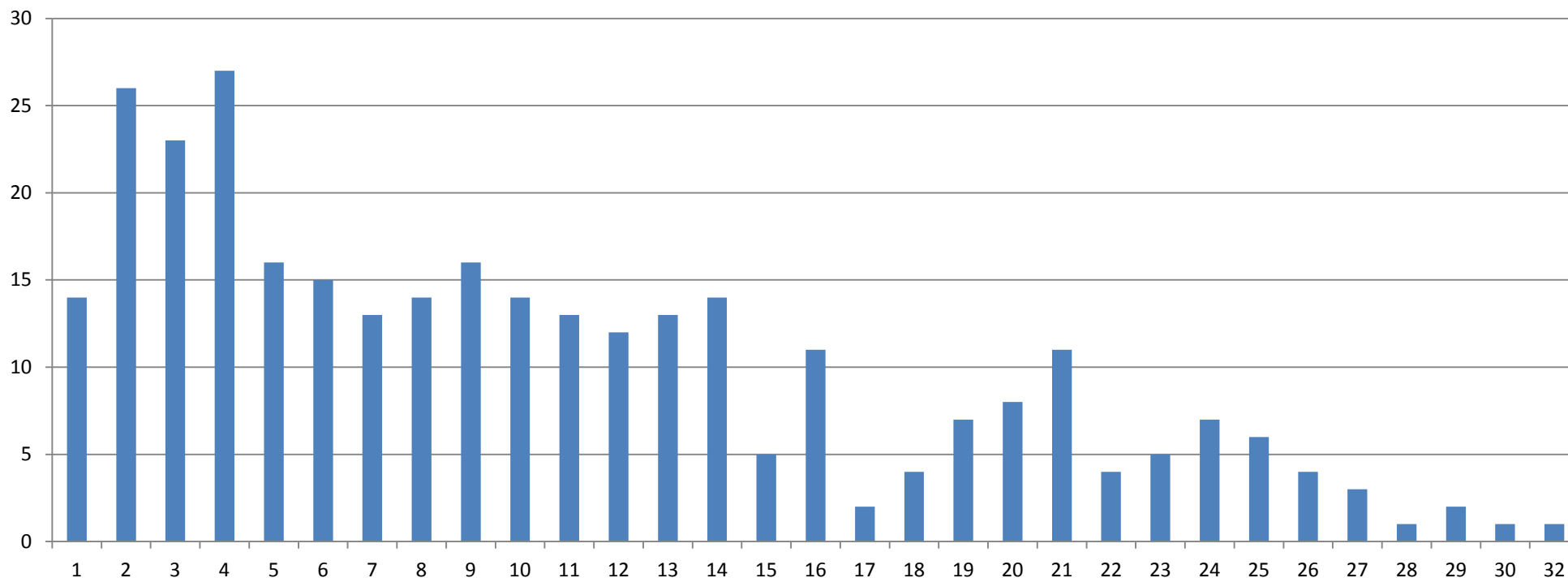
d. Misfuel Incidents by Contamination Type



- Gasoline: Gasoline was identified/named
- Bad Fuel: No specified information, “misfuel”, “contaminated”, “bad fuel”, “milky”, “smells bad”

2. Field Data

d. Misfuel Incidents by Months in Service



- Most misfuel incidents happen during early vehicle life
- Customers likely are “not used” to driving a diesel vehicle

2. Field Data

d. Misfuel Incidents – Geographic Distribution

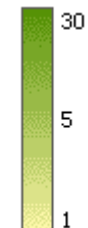
Misfuel VINs by State



Note:

Distribution generally
matches with „incident
map“

Count of
Misfuels
by State



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2. Field Data

d. Fuel Sampling – iPal Measurements

iPal-Measurements

- In August 2010 Volkswagen introduced the iPal test as a quick indication for workshops whether there is gasoline in the diesel fuel
- Volkswagen Laboratory determined that some of the low gas-% measurements (around 1%) were free of additional gasoline, other contained amounts of gasoline while iPal measurements were in the same range.
- Only one sample with higher gasoline content (iPal: 10%) was still available and confirmed by the lab with measurement of the flash point and gas chromatography.



Conclusion

- The iPal machine seems to be able to detect higher amount contamination with gasoline,
- Low amount measurements are not reliable, possibly below the machine's tolerance.

2. Field Data

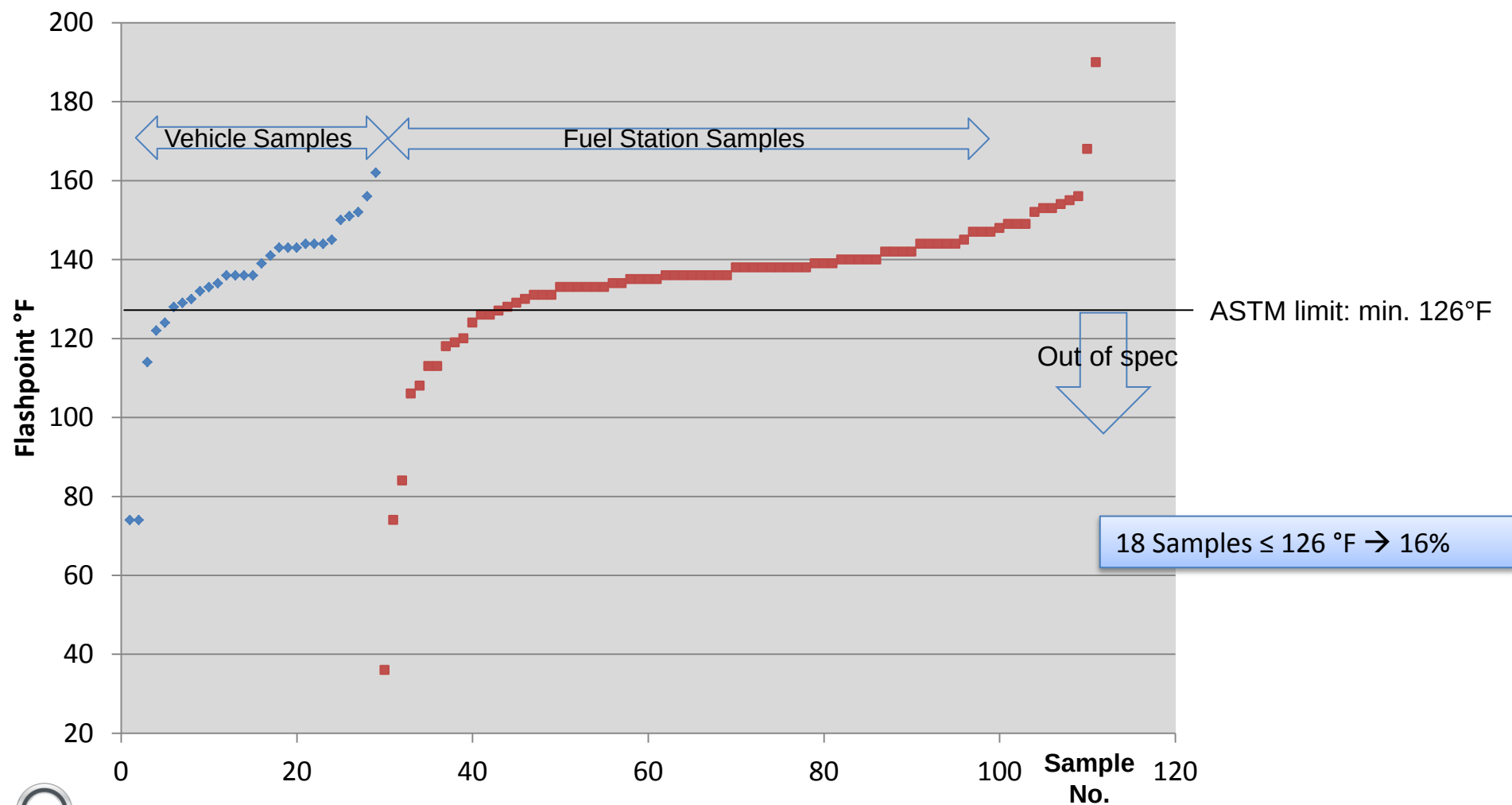
d. VW Fuel Survey - Targets

Volkswagen decided to conduct its own fuel survey with customer vehicle coming into dealerships for any event (maintenance, wheel change, repairs, etc).

- Create a statistical basis about what actually is in customer's fuel tank
 - Gasoline, biodiesel, water content, etc.
 - Measurement of viscosity, lubricity and flash point (etc)
- Create a statistical basis about what is sold from fuel stations
 - Gasoline, biodiesel, water content etc.
 - Measurement of viscosity, lubricity and flashpoint (etc)

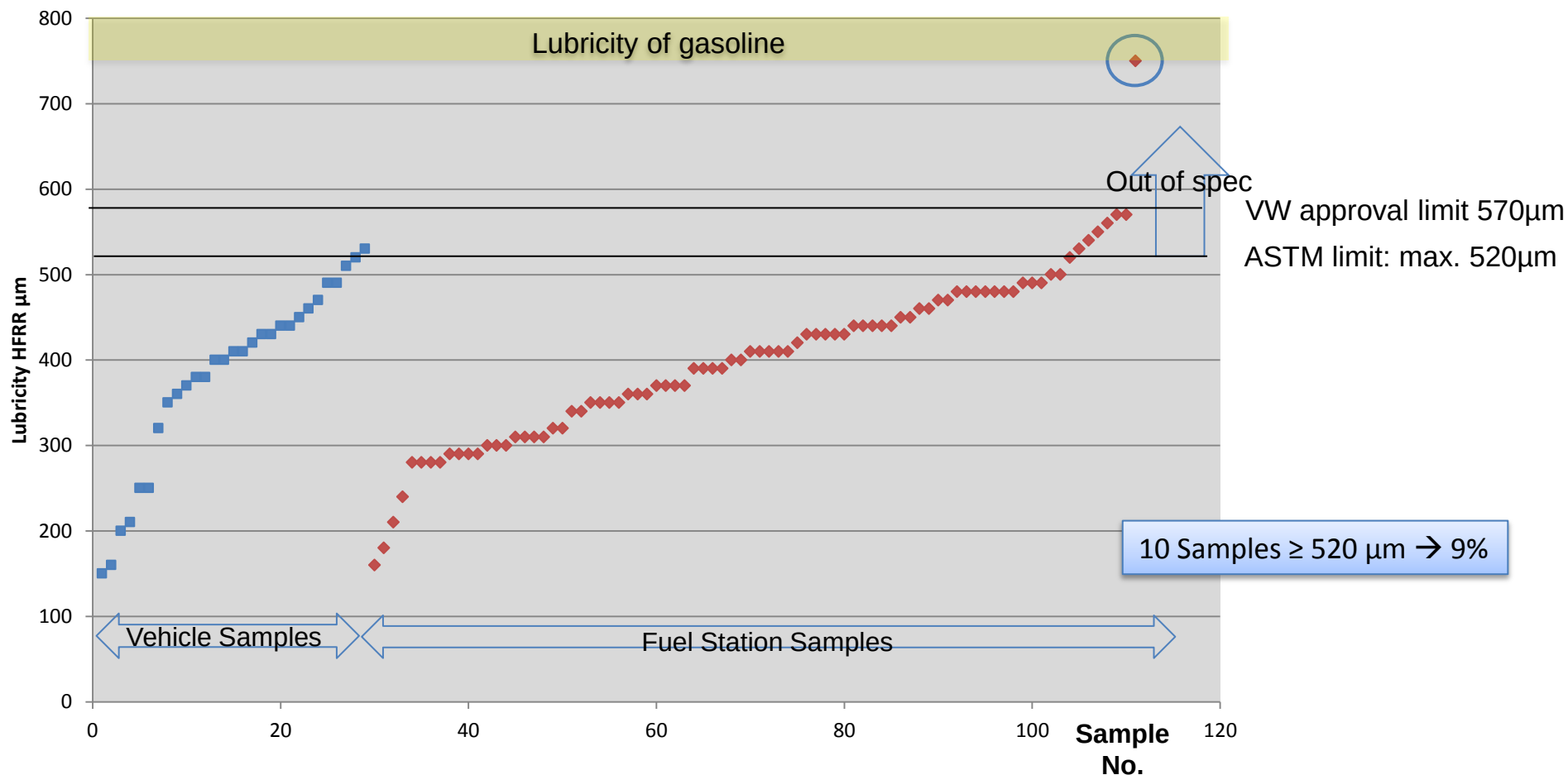
2. Field Data

d. VW Fuel Survey – Sample Results „Flashpoint“



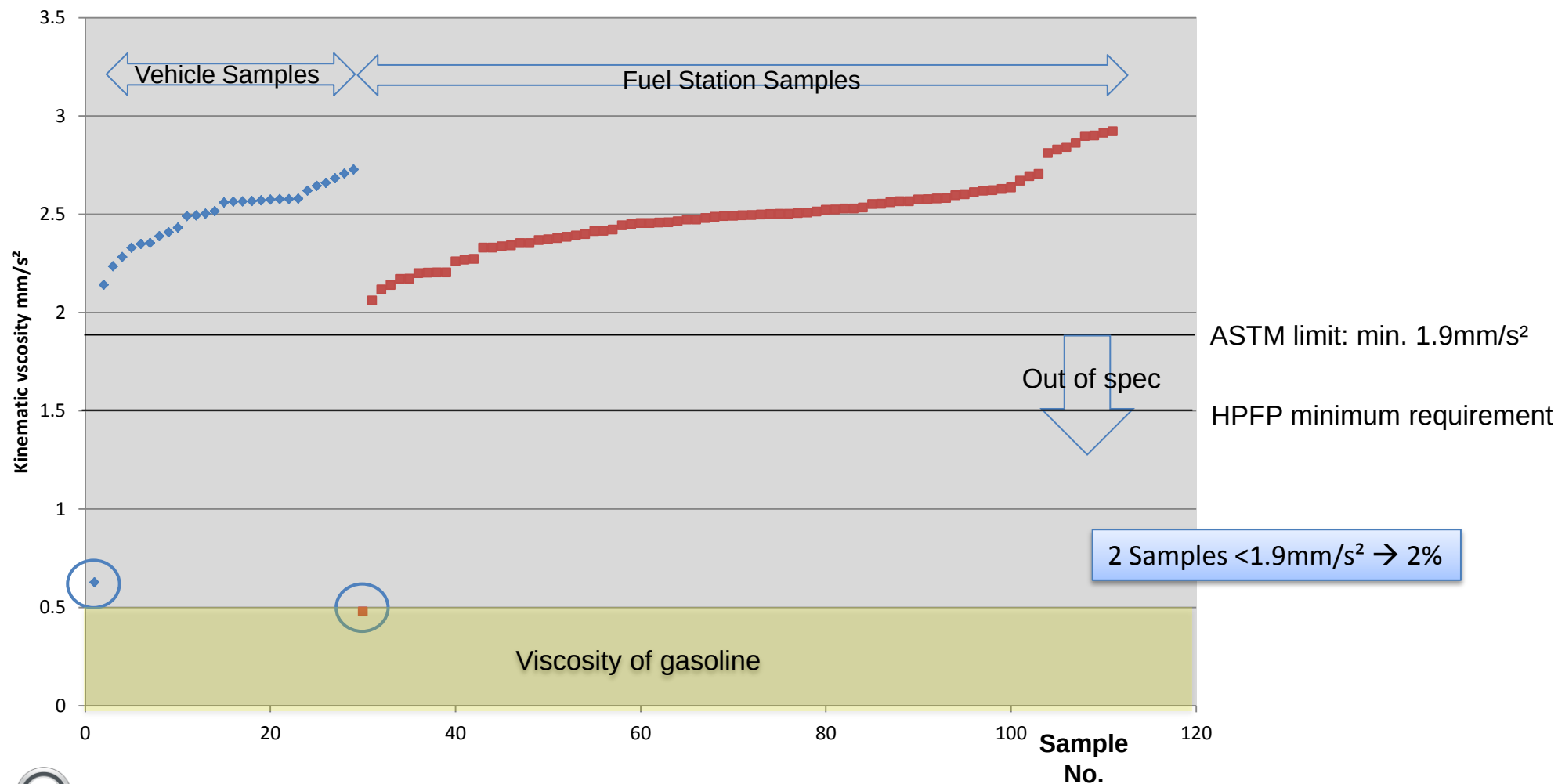
2. Field Data

d. VW Fuel Survey – Sample Results „Lubricity/HFRR“



2. Field Data

d. VW Fuel Survey – Sample Results „Viscosity“



2. Field Data

d. VW Fuel Survey - Findings

By end of April, 111 samples have been analyzed in an independent external laboratory in the U.S.

Out of Spec	Vehicle Sample	Fuel Station Sample	Total	Total w/o dup
Lubricity	1	7	8	21
Viscosity	1	1	2	
Flash Point	5	11	16	

Summary

- In total 21 of 111 samples were found to be out of spec, 5 of them far out of spec
→ This is more than double compared to the AAM gas station survey
- 1 Sample from a fuel station apparently had (pure) gasoline in the diesel tank (IL)
- 1 Sample from a car had a viscosity far below spec.
→ 2 samples (or 1.8%) have properties (viscosity, HFRR) that will damage the HPFP
the fuel found “has nothing” from ASTM D975 standard diesel

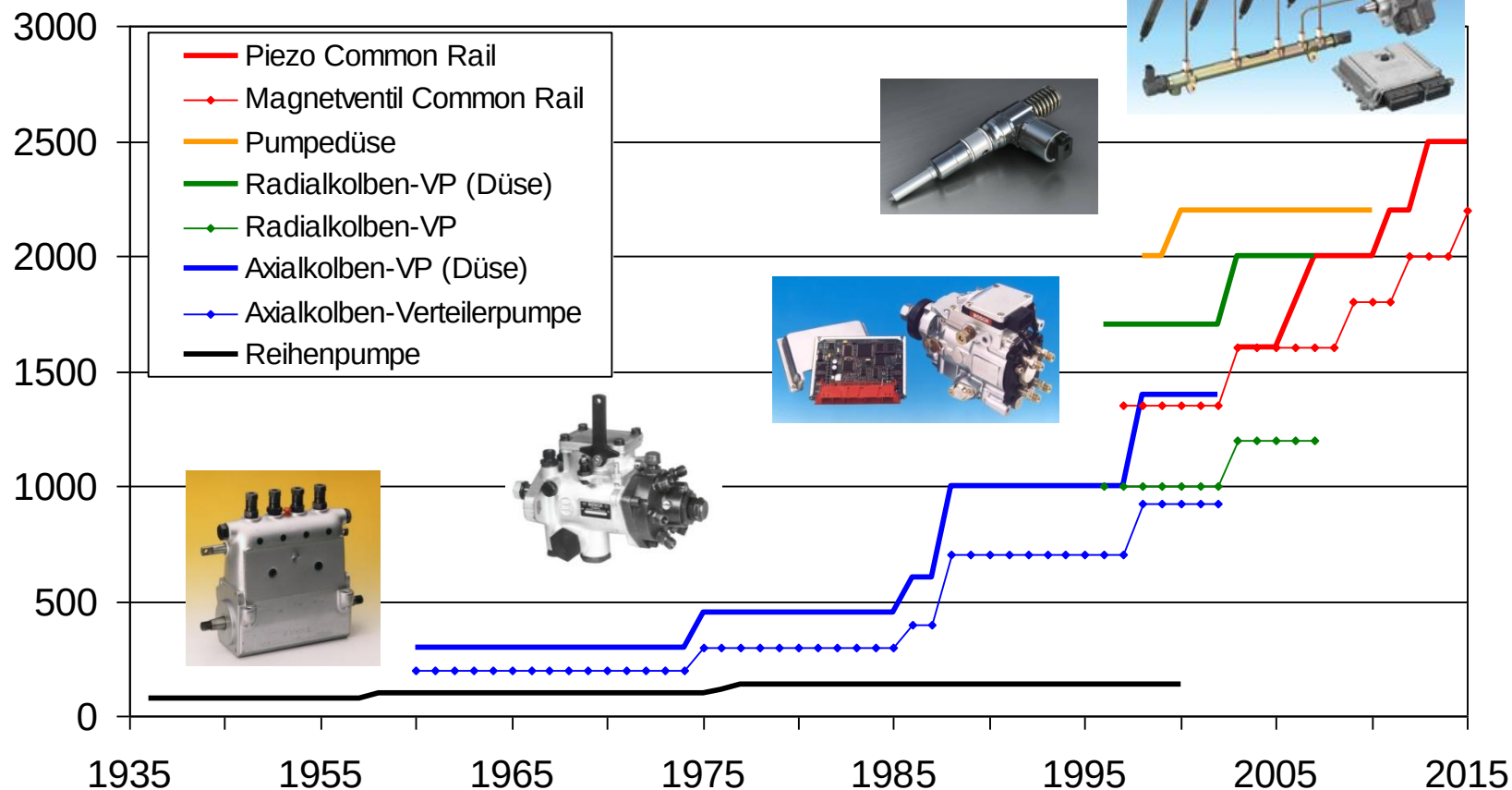
3. Diesel Fuel Injection System / Components

Agenda

- a. Brief overview of common designs for light vehicles
 - Historical perspective, including effects of regulation
- b. Common rail systems (CRS)
 - Design evolution
 - Vehicles using CRS - past & present, VW & peers (if known)
- c. Description of subject CRS design
 - Basic operation and differences from prior generation system
 - Failsafe operating modes and DTCs
- d. Bosch – review linked documents and provide copies of any related material
 - Diesel Fuel Lubricity, Requirements for Light Duty Fuel Injection Equipment, CARB Fuels Workshop, Feb 20, 2003
 - Fuel Requirements for Diesel Fuel Injection Systems, Diesel Fuel Injection Equipment Manufacturers Common Position Statement 2009

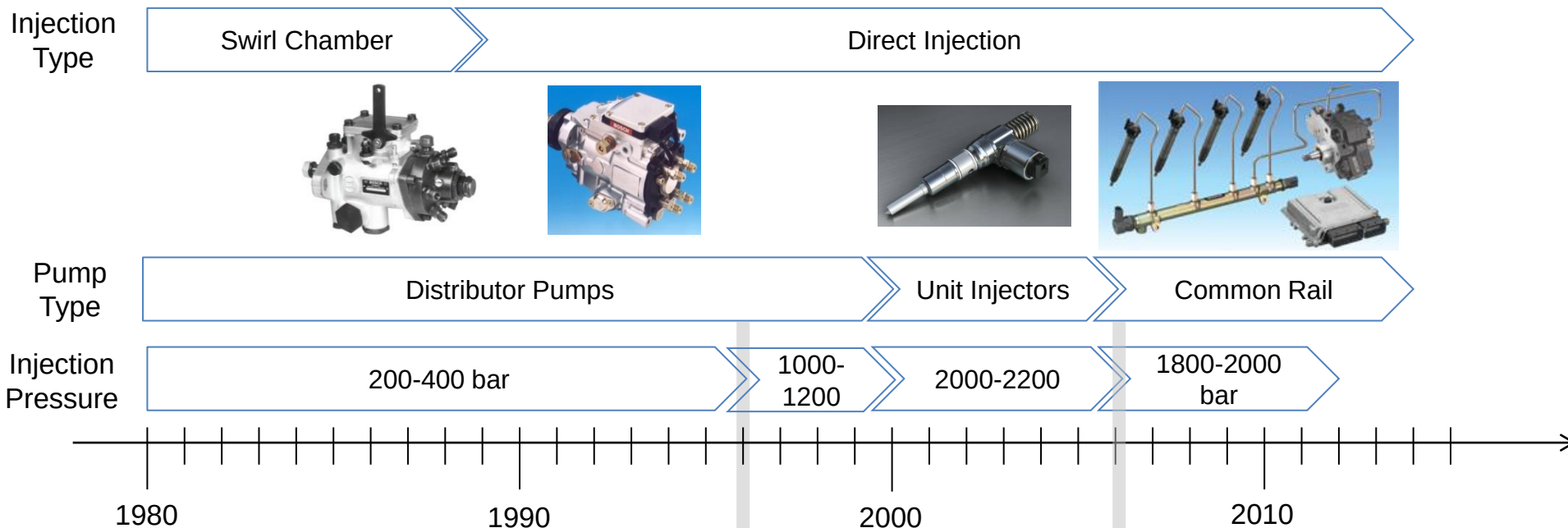
3. Diesel Fuel Injection System / Components

a. Design Overview – Historical Perspective



3. Diesel Fuel Injection System / Components

a. Design Overview – Historical Perspective – Effects of Regulation



Emission Requirements

NOx (g/mi)	1.0	0.4	0.05
Particle Mass (g/mi)	0.2	0.08	0.01
NMHC (g/mi)	Not specified	0.25	0.125
		0.075	

3. Diesel Fuel Injection System / Components

b. CRS Design Evolution – Vehicles using Common Rail Past and Present

Design Evolution

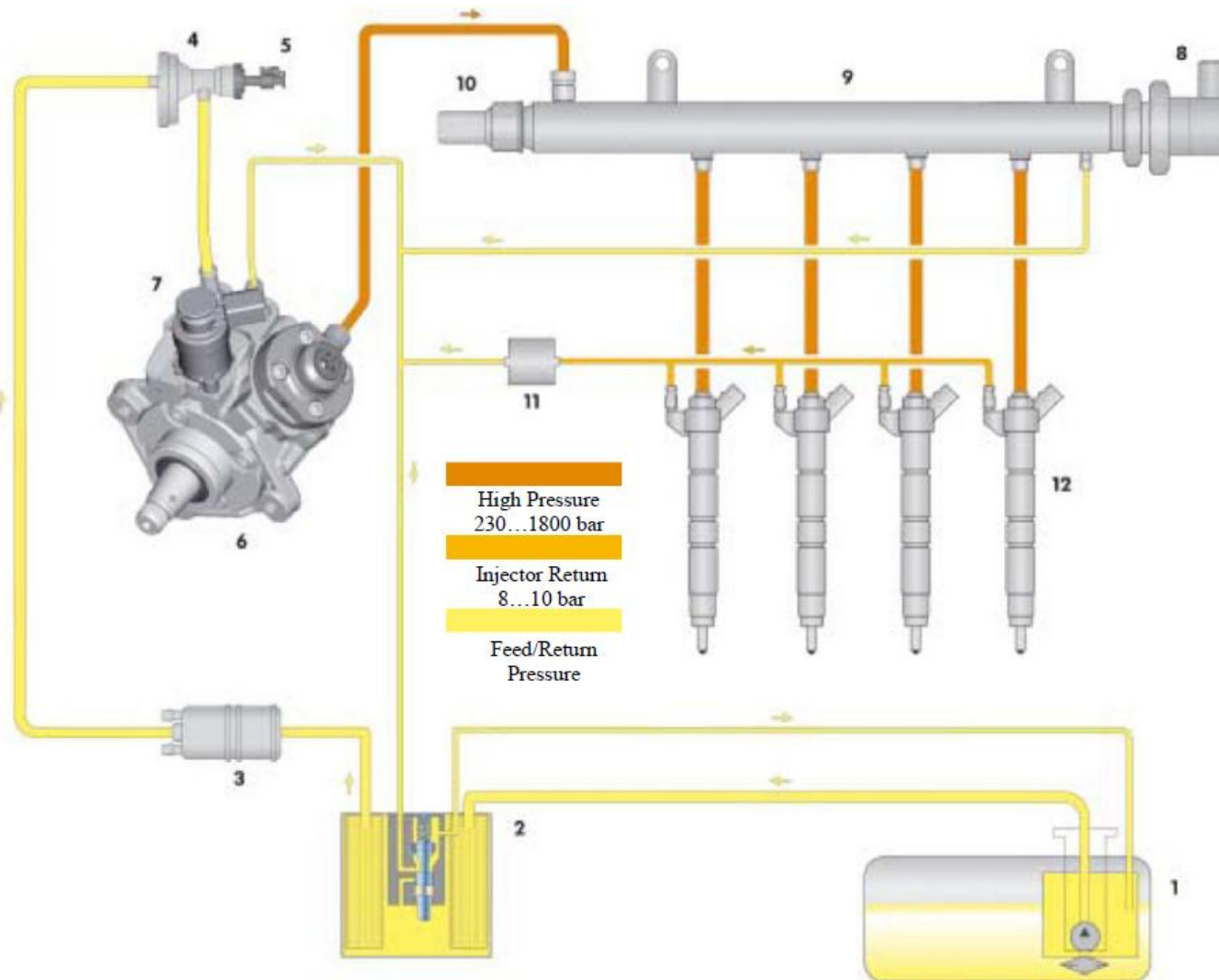
- Current common rail system is 1st generation of common rail for Volkswagen
- Predecessor design was unit injector (“Pumpe-Düse”) system

Vehicles with Common Rail System

- No former VW/Audi vehicles use a common rail system
- Current US models are Jetta, Golf, Touareg, Audi A3 and Q7 with TDI Clean Diesel engine

3. Diesel Fuel Injection System / Components

c. Basic Operation – System Structure (Schematic) – 1st (Current) Generation



- 1) Fuel delivery unit (in-tank fuel pump)
- 2) Fuel filter with pre-warming valve
- 3) In-line fuel pump (or auxiliary pump)
- 4) Strainer (included in the fuel metering unit, #7 below)
- 5) Fuel temperature sensor
- 6) High pressure fuel pump (HPFP)
- 7) Fuel metering unit
- 8) Pressure regulation valve
- 9) Common rail
- 10) Pressure sensor
- 11) Pressure retention valve
- 12) Injectors

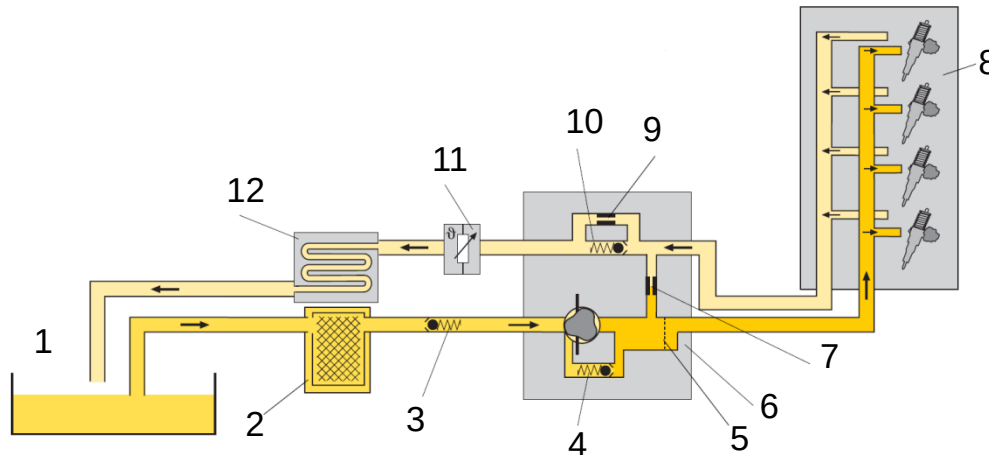
3. Diesel Fuel Injection System / Components

c. Basic Operation (Narrative)

- The in-tank fuel pump (1) delivers the diesel fuel from the fuel tank to the fuel filter (2), located within the engine compartment.
- A secondary “in-line” fuel pump (3) provides additional pressure to the feed line.
- The fuel passes a fuel temperature sensor (5) and enters the HPFP (6) through a strainer (4).
- The HPFP increases the fuel pressure up to 1,800 bar / 26,107 psi and feeds the fuel to the “common rail.” (9)
- The actual pressure inside the common rail is controlled by a pressure sensor (10) and a regulation valve (8), depending on engine operating load and fuel demand requirements.
- The engine control unit operates the fuel injectors (12) and provides for multiple injections (when necessary) during one combustion cycle.
- Excess fuel is returned via return lines to the fuel filter (2).
- The pressure retention valve (11) in the return line provides a reference pressure for each injector during operation and prevents the injectors from running dry (fuel being drained from the line) when the engine is off.
- Inside the fuel filter (2), a temperature valve determines whether fuel is redirected to either the HPFP or to the fuel tank, dependent on operating and ambient temperatures.

3. Diesel Fuel Injection System / Components

c. Prior Generation: Unit Injector (Pumpe-Düse) System - Properties

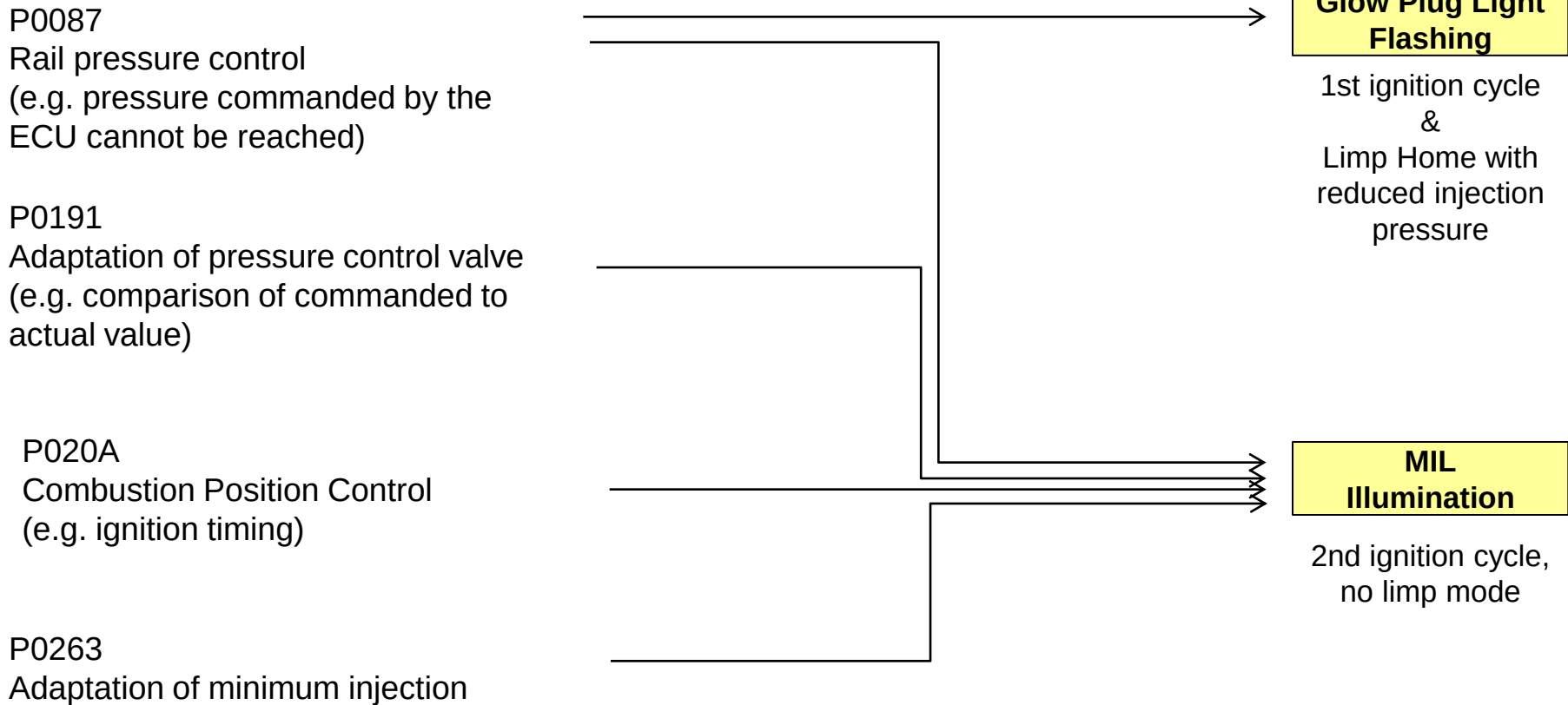


- 1) Fuel Tank
- 2) Fuel Filter
- 3) Check Valve
- 4) Pressure Limiting Valve
- 5) Strainer
- 6) Fuel Pump
- 7) Ventilation Valve
- 8) Cylinder Head
- 9) Ventilation Bypass
- 10) Pressure Limiting Valve
- 11) Fuel Temperature Sensor
- 12) Fuel Cooler

- PD-System consists of a combined pump-injector unit
- High pressure is created where it is needed (avoiding the need of high pressure fuel lines)
- Extremely high pressure (up to 2050 bar) provides optimal combustion, high torque/power output, high fuel economy.
- Minuspunkte (reasons to change to a CR system)
- One pre-injection, No post-injection possible
- Not compatible with newer exhaust after treatment and their regeneration cycles (does not comply with current emission requirements)
- Not as comfortable (noise, vibrations) as CR-engine

3. Diesel Fuel Injection System / Components

c. Failsafe Operating Modes and DTCs – DTCs stated in about 30% of the Incidents



3. Diesel Fuel Injection System / Components

c. Limp Home

- The HPFP as mechanical component has no electrical diagnosis and no “own” failsafe operating/limp home mode
 - Deviations from normal operation are detected by sensors in the common rail system (pressure sensor, regulation valve) and the injecting timing / running of the engine
 - A limp home can be caused by the ECU when operation parameters are far out of normal operation limits, accompanied with warning lights and the instruction to immediately seek assistance
-
- For example if rail pressure drops (P0087) – in case of a malfunctioning pressure regulation valve - the ECU will limit the injection pressure and go into a limp home mode with reduced engine power. The glow plug light will flash to warn the customer and the MIL will illuminate if the fault condition is still present in the next ignition cycle.
 - Customers can perceive this as a “loss of power”
 - If the minimal pressure (80-100 bar) cannot be retained the engine could possibly stall

3. Diesel Fuel Injection System / Components

d. CARB Fuels Workshop Document 2003

The document was published in a phase where lubricity was

- already defined in the EU diesel fuel standard EN590: HFRR < 460 µm
- going to be defined in the US diesel fuel standard ASTM D975

Objective of the paper: Convince stakeholders in ASTM standardization process to adopt EU test procedure and threshold

Benefit: Unification would

- simplify the development and release process for FIE
- avoid necessity to develop components specific/adapted for the US market

Approach: Disclosure of durability test results with different pump types (state of the art when the report was published)

- Successful tests when using 460µm HFRR diesel fuel
- Failed tests when using 650µm HFRR diesel fuel

3. Diesel Fuel Injection System / Components

d. CARB Fuels Workshop Document 2003

- Result: Activities were only successful in part
- HFRR was incorporated in ASTM D975
 - but limited to 520 µm only
- Consequence: Robustness improving measures (“low lubricity package”) had to be / and were applied to components originally developed for European EN590 fuel when use of ASTM D975 fuel was intended

3. Diesel Fuel Injection System / Components

d. Fuel Injection Manufacturers' Position Paper 2009

- The 2003 CARB fuels workshop paper was a comment by the fuel injection equipment manufacturers on the definition of the ASTM D975 standard
- The 2009 update of the common position statement was published to include a further comment on biodiesel and in addition sought to harmonize the lubricity requirements from the ASTM standard with the European standard at the level of the European standard.
- However, the ASTM standard remains different and allows a WSD up to 520µm for the US (460µm in Europe).
- Volkswagen TDI Clean Diesel engines are designed to operate on the higher WSD.

4. High Pressure Fuel Pumps

- a. Brief description of different HPFP designs
- b. Subject HPFP operation
- c. Design change history
- d. Durability testing
- e. Internal investigations
 - Chronology
 - Warranty return analyses (bucketing by failure mechanisms?)
 - Discuss 8D reports
 - Discuss current status and open/planned actions
- f. Failure mechanisms / failure modes
 - Misfuel (by customer or fuel station, low to high %)
 - Contaminated / Bad fuel (from filling station)
 - Initial Damage and progression
 - Additional causes
 - Parameters – cause & effect
- g. Misfuel scenarios
- h. Running out of fuel

4. High Pressure Fuel Pumps

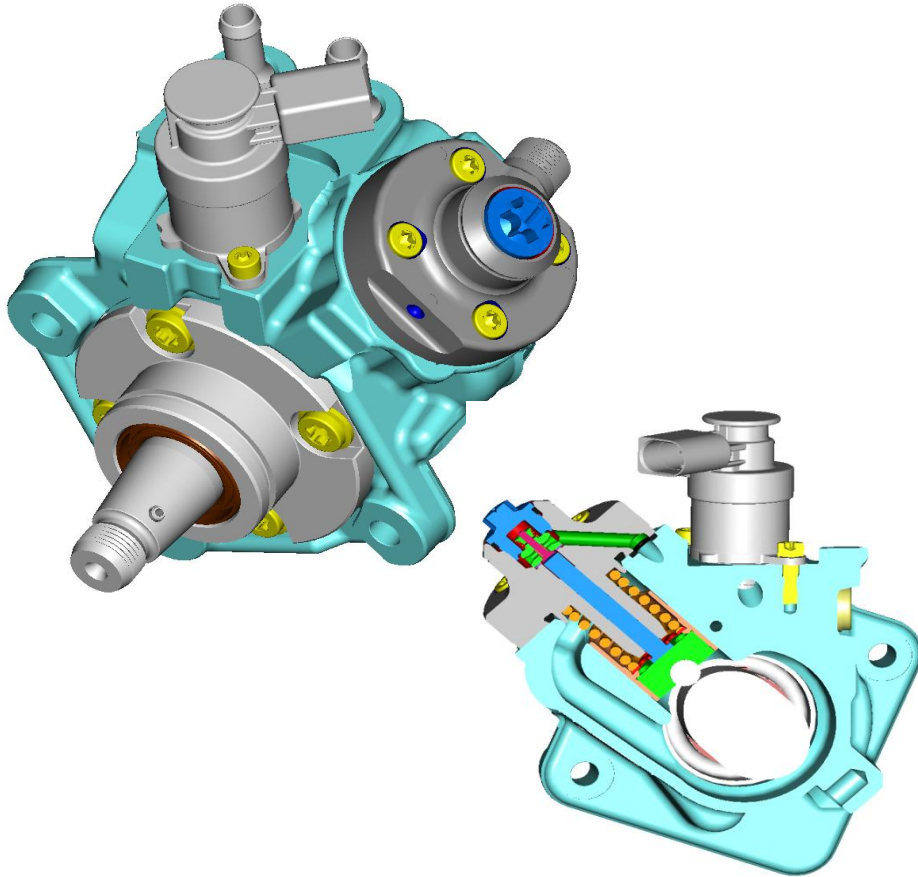
a. Brief Description of Different HPFP Designs

Two approaches in regard to the design:

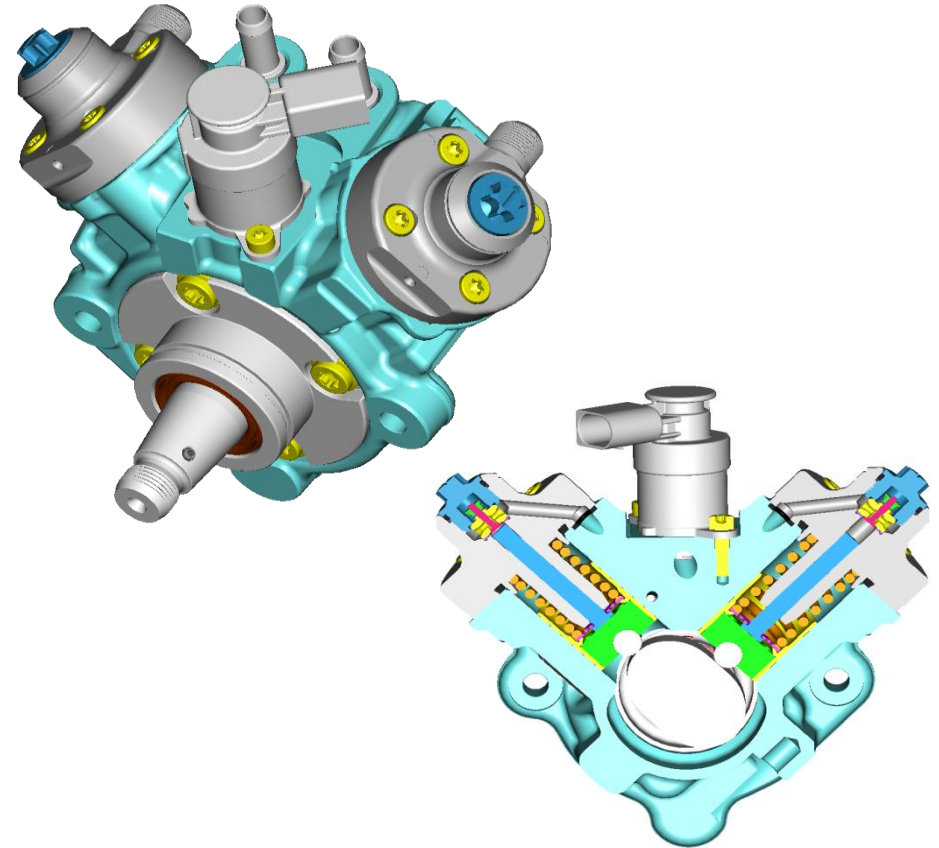
- 4 and 6 cylinder engine HPFPs
 - 1 and 2 piston HPFP
- European and U.S. HPFP
 - Original European version without low-lubricity package
 - When approving for the U.S. (SOP for US vehicles) most low-lubricity measures were carried over to the EU HPFP for unification

4. High Pressure Fuel Pumps

a. Brief Description of Different HPFP Designs – 4 vs. 6 Cylinder Engine HPFP

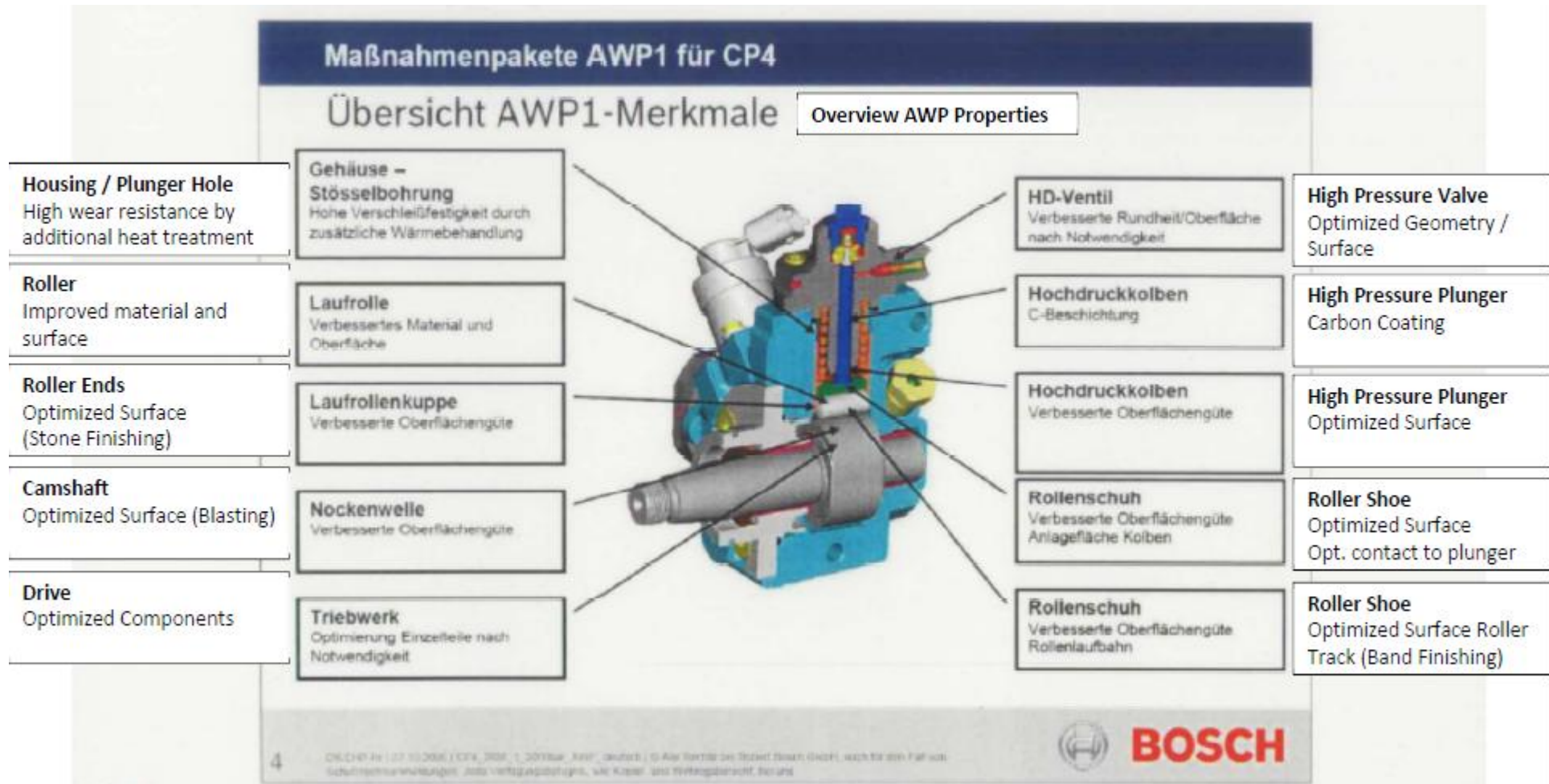


HPFP for 4 cylinder engine
- One piston



HPFP for 6 cylinder engine
- Two pistons, 90° position
- Pistons and Drive identical to one piston HPFP

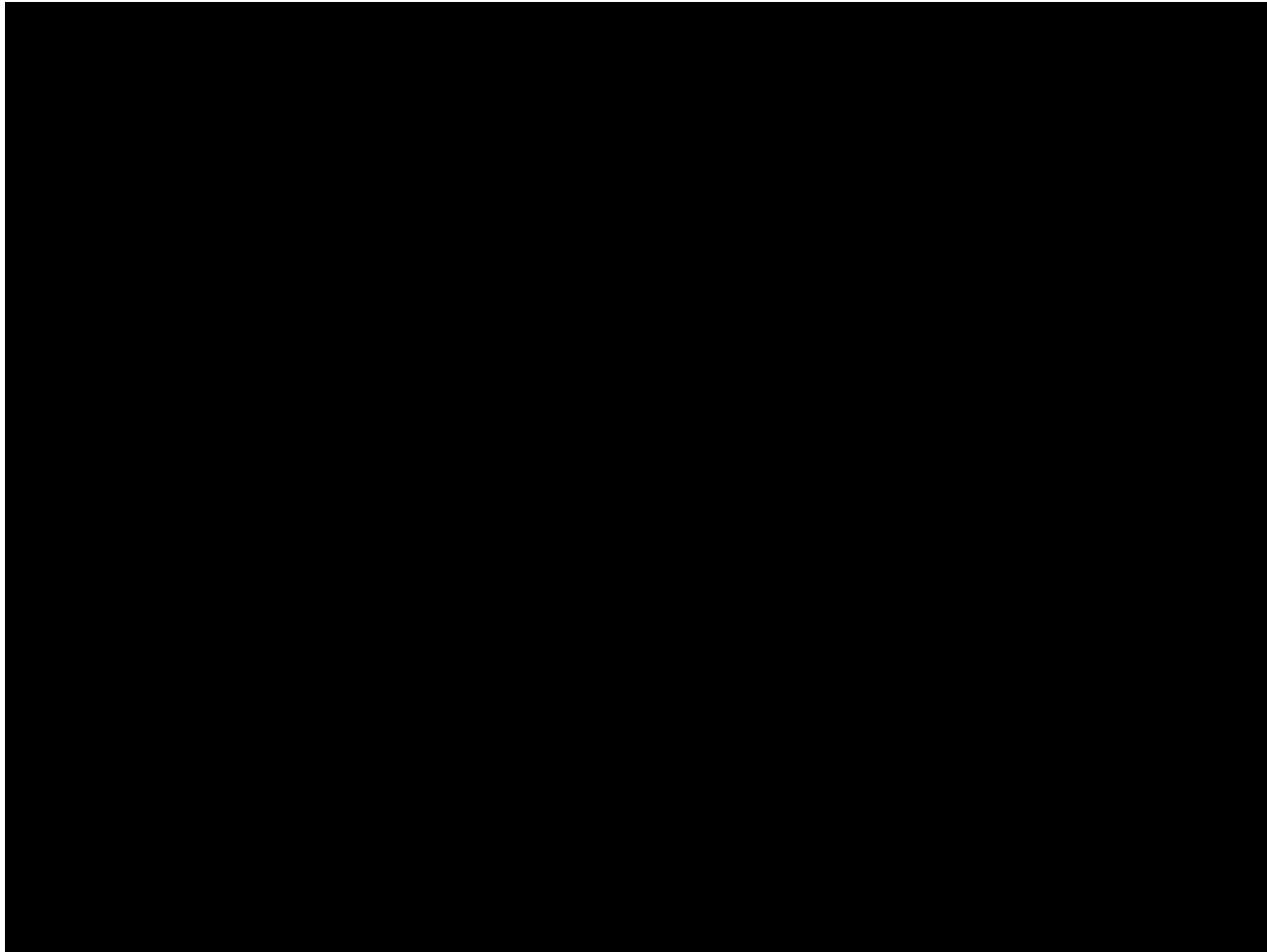
a. Brief Description of Different HPFP Designs – U.S. vs. European Version



- European pump does not incorporate Coated Plunger (only difference)
- Other measures incorporated into EU version for reasons of production depth

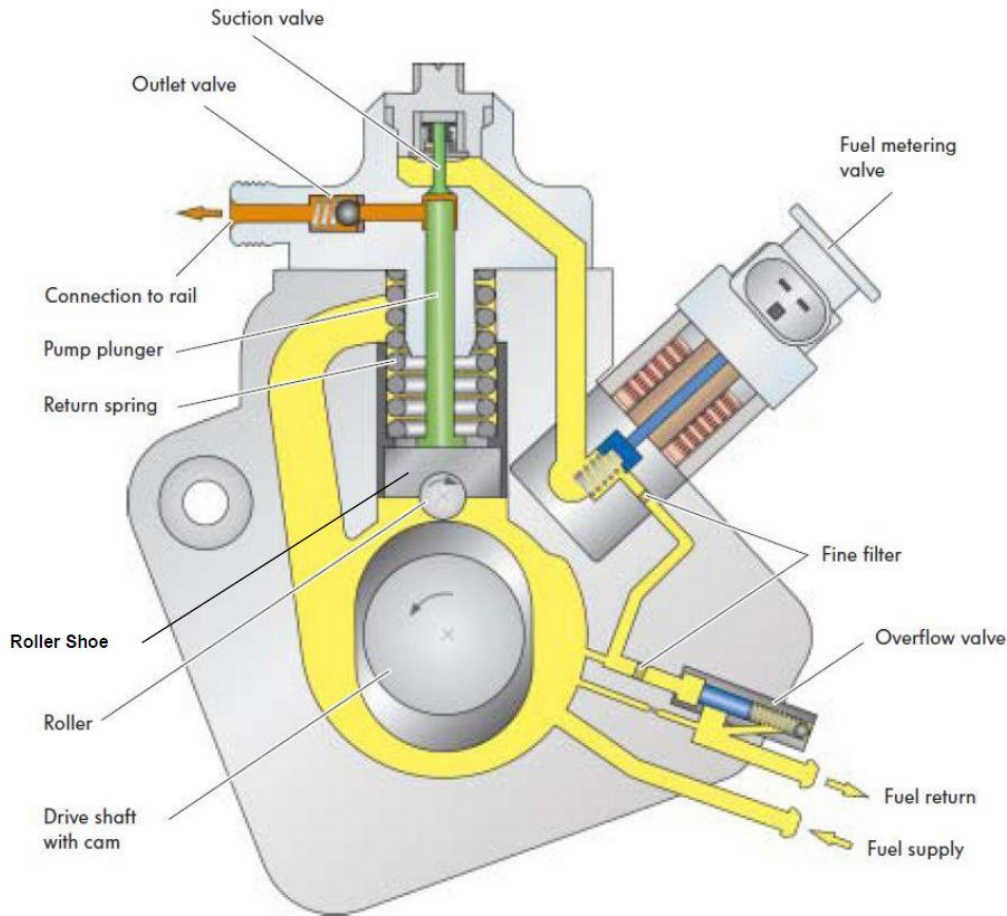
4. High Pressure Fuel Pumps

b. HPFP Operation (Animated)



4. High Pressure Fuel Pumps

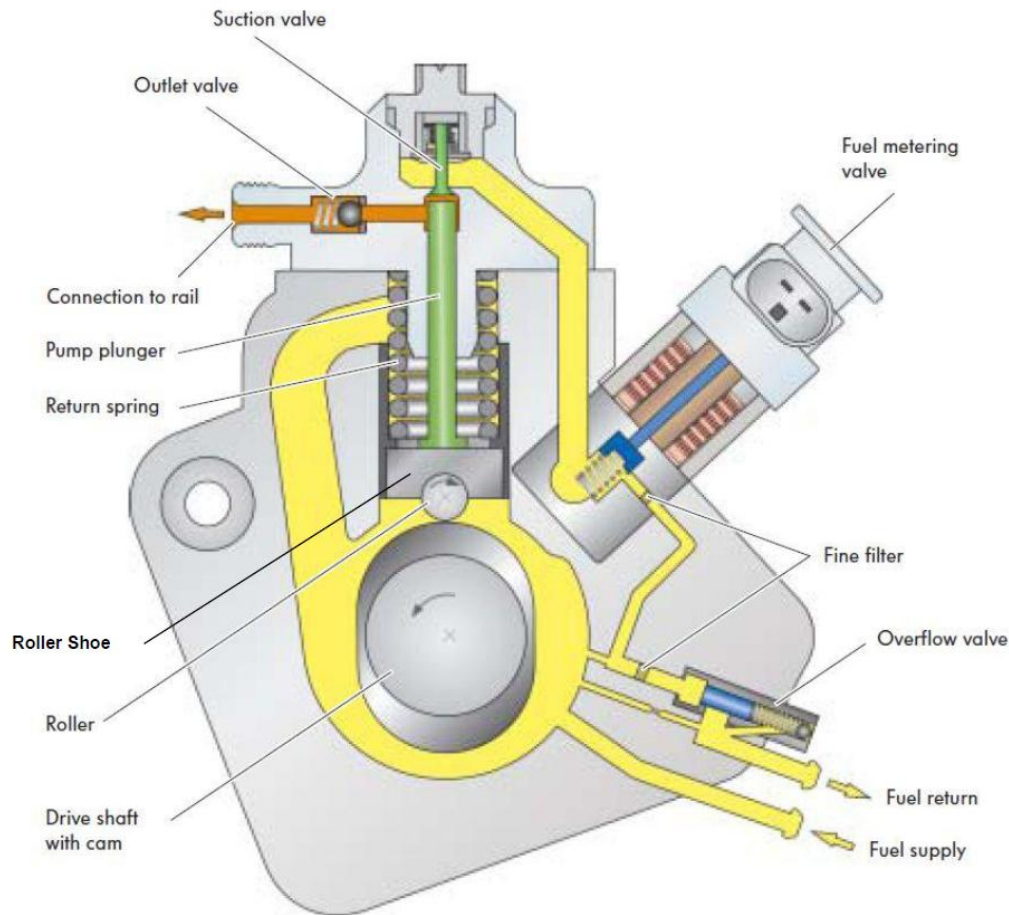
b. HPFP Operation



- As the plunger moves down, the suction valve opens and draws fuel into the high pressure chamber. As the camshaft lobe drives the plunger up, the suction valve closes, raising the pressure of the fuel within the high pressure chamber. The outlet valve then opens, feeding the high pressure fuel to the “common rail.”
- The pump is driven by a dual lobe camshaft. The camshaft is in constant contact with a roller, which is retained in position by a spring loaded roller shoe. The roller shoe provides the contact point between the roller and pump plunger. One revolution of the camshaft provides two actuations of the pump plunger.

4. High Pressure Fuel Pumps

b. HPFP Operation – Diesel as Lubricant



Why diesel as lubricant

- No gasket between moving parts could withstand pressure gradient of approx. 2000 bar
 - Lubrication with engine oil would cause
 - diesel fuel mixed into the engine oil (causing oil thinning) or
 - engine oil contaminating the diesel fuel (affecting vehicle emissions)
- both consequences are not acceptable

→ Addressed in design by using diesel fuel as lubricant

4. High Pressure Fuel Pumps

c. Design Change History

Status CP4 Triebwerksschäden , Stand KW03/11

Nr.	Maßnahmen zur Vermeidung von Triebwerksschäden	Einführung FeP		Einführung JhP	
		Tagesdatum	KW	Tagesdatum	KW
1	keine Wiederverwendung von Stößel nach i.O. Einpressprozess	10.05.2007	KW19/07	31.01.2008	KW04/08
2	Klick-Klack-Prüfung vor Ablieferung	10.05.2007	KW19/07	31.01.2008	KW04/08
3	Klick-Klack-Prüfung	14.05.2007	KW20/07	31.01.2008	KW04/08
4	Delta T und Delta Tmax Prüfung an Prüfbank	23.05.2007	KW21/07	31.01.2008	KW04/08
5	Klick-Klack-Prüfung am Bandende Montage	29.05.2007	KW22/07	31.01.2008	KW04/08
6	neuer Umschaltvorgang zw. Spülen und prüfen	30.05.2007	KW22/07	31.01.2008	KW04/08
7	mitlaufende Geräuschmessung	18.06.2007	KW25/07	31.01.2008	KW04/08
8	Entfall Wiederholungsprüfung	20.06.2007	KW25/07	01.12.2007	KW48/07
9	Optimierung Prüfprogramm	09.07.2007	KW28/07	31.01.2008	KW04/08
10	Zylinderkopfmontage	23.07.2007	KW30/07	01.12.2007	KW48/07
11	trockenes Einpressen Rollenschuh	23.07.2007	KW30/07	06.02.2008	KW05/08
12	unbeschichteter Federteller (Kunde C)	23.07.2007	KW30/07	31.01.2008	KW04/08
13	Einführen Verweilzeit bei Montage Rollenschüssel	28.08.2007	KW35/07	06.02.2008	KW05/08
14	Verlängerung Prüfpunkt hohe Last	01.10.2007	KW40/07	31.01.2008	KW04/08
15	Prüfpunkt V7.2 (Kunde C)	16.11.2007	KW46/07	31.01.2008	KW04/08
16	verbesserte Sichtprüfung Rollenschuh	01.12.2007	KW48/07	31.01.2008	KW04/08
17	Reibwertprüfung +/-10%	01.12.2007	KW48/07	31.01.2008	KW04/08
18	Stößellagenauftrag in Montage	01.12.2007	KW48/07	31.01.2008	KW04/08
19	neuer Sichtprüfkatalog Rollenschuh	02.01.2008	KW01/08	20.01.2008	KW02/08
20	Prüfprogramm V7.2 (VW) Sichtprüfkatalog Rollenschuh	11.01.2008	KW02/08	31.01.2008	KW04/08
21	Prüfprogramm V7.2 (Audi)	01.02.2008	KW05/08	31.01.2008	KW04/08
22	Umstellung der Laufrolle bei den Typen ...507/...508	17.03.2008	KW12/08	31.01.2008	KW04/08
23	Haarlinealprüfung Sichtprüfkatalog Rollenschuh	07.04.2008	KW15/08	07.04.2008	KW14/08
24	Reinigungstuch bei Haarlinealprüfung	01.05.2008	KW18/08	01.05.2008	KW17/08
25	Sichtprüfung der Laufrolle nach C	29.10.2008	KW44/08	29.10.2008	KW44/08
26	Optimierung der C-Beschichtung	24.11.2008	KW48/08	06.05.2009	KW19/09
27	Umstellung der Laufrolle bei den Typen ...507/...508	12.12.2008	KW50/08	12.12.2008	KW50/08
28	neue Wasch- und Transportrahmen der Laufrolle	16.03.2009	KW12/09	16.03.2009	KW12/09
29	geändertes Aufnahmewerkzeug RS beim Einpressen des Stößelkörpers	24.11.2008	KW48/08	06.05.2009	KW19/09
30	Karbonabdeckungen / Halterungen in Anlage N für Rollenschuh	12.12.2008	KW50/08	12.12.2008	KW50/08
31	Karbonabdeckungen / Halterungen in Anlage O für Rollenschuh	16.03.2009	KW12/09	16.03.2009	KW12/09
32	Kamerasystem zur Erkennung Metallspritzer auf Rollenschuh	02.12.2009	KW49/09	02.12.2009	KW49/09
33	System installiert / Ausprobe	09.03.2010	KW10/10	09.03.2010	KW10/10
34	Serieneinführung frühestens ab Mitte	26.10.2010	KW43/10	18.11.2010	KW45/10
35	Einführung C2.1 Schicht - anstelle C3	02.12.2009	KW49/09	02.12.2009	KW49/09
36	optimierte Substrathalter zur Vermeidung von Beschädigungen	09.03.2010	KW10/10	09.03.2010	KW10/10
37	Einführung Robustheitspaket RP2 in FeP und JhP (2-Stempler)	26.10.2010	KW43/10	18.11.2010	KW45/10

Optimization prior
to SOP

US-
SOP

Optimization after
SOP

Item 33 – Coating Change

Item 36 – Optimized Tolerances, Coating Change

Item 37 – Optimized HPFP cooling (2-piston pump)

All other items are optimizations of the
manufacturing process to reduce production scrap

Legende	
Maßnahme eingeführt	
Einführung im Plan	
Einführungstermin überschritten	
Umsetzung nicht Ziel-führend, bzw. Effek-tivität wird geprüft	

Diesel Systems

1

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4. High Pressure Fuel Pumps

b. Durability Testing

Main Part of the development including extensive component and vehicle testing was done with European specification vehicles.

An additional validation then was performed with US specification vehicles and US fuels

Engine bench tests:

- EU 27,890 hours
- US 26,684 hours

Component bench testing (Bosch validation)

- US 9,500+ hours

Vehicle durability testing

- EU 4,220,000 Miles with 124 vehicles
- US 1,600,000 Miles with 37 vehicles in the US

4. High Pressure Fuel Pumps

d. Durability Testing

Tests are conducted

- On several internal standard test cycles (bench) and tracks (proving grounds)
- Different testing/approval Fuels (standard and „worse“ fuels)
- Local market fuels used during US approval
- Test reflect a wide range of operating conditions covering the whole vehicle life

HFRR-values

Testing fuels have HFRR-values up to 570µm (in vehicle) and must not result in premature damage, otherwise HPFP would not have been approved.

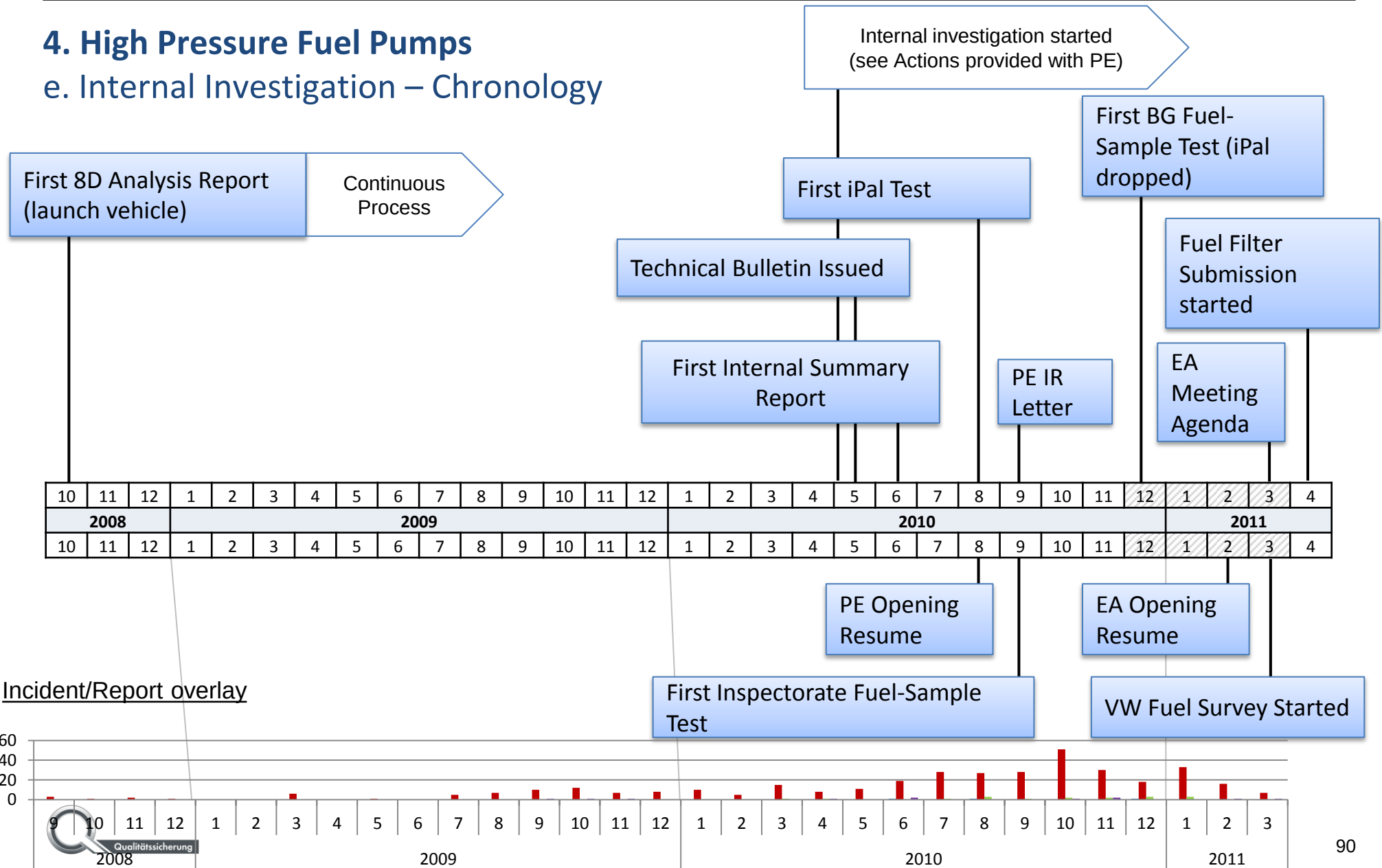
Gasoline contamination

Performance/durability with systematic gasoline contamination was not tested and is not part of the development process – engine is not designed to run on gasoline, various circumstances of misfueling would be infinite and speculative

Durability Requirement

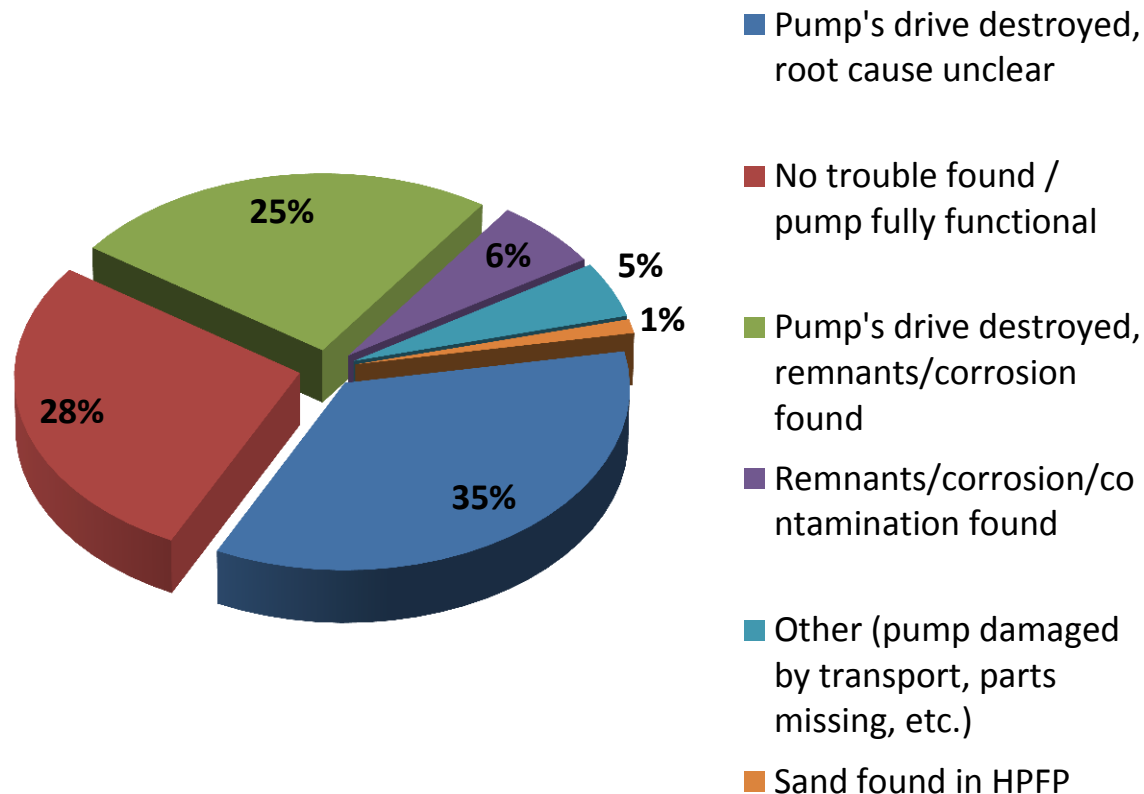
4. High Pressure Fuel Pumps

e. Internal Investigation – Chronology



4. High Pressure Fuel Pumps

e. Internal Investigation – Warranty Return Analyses / Bosch 8D-Reports

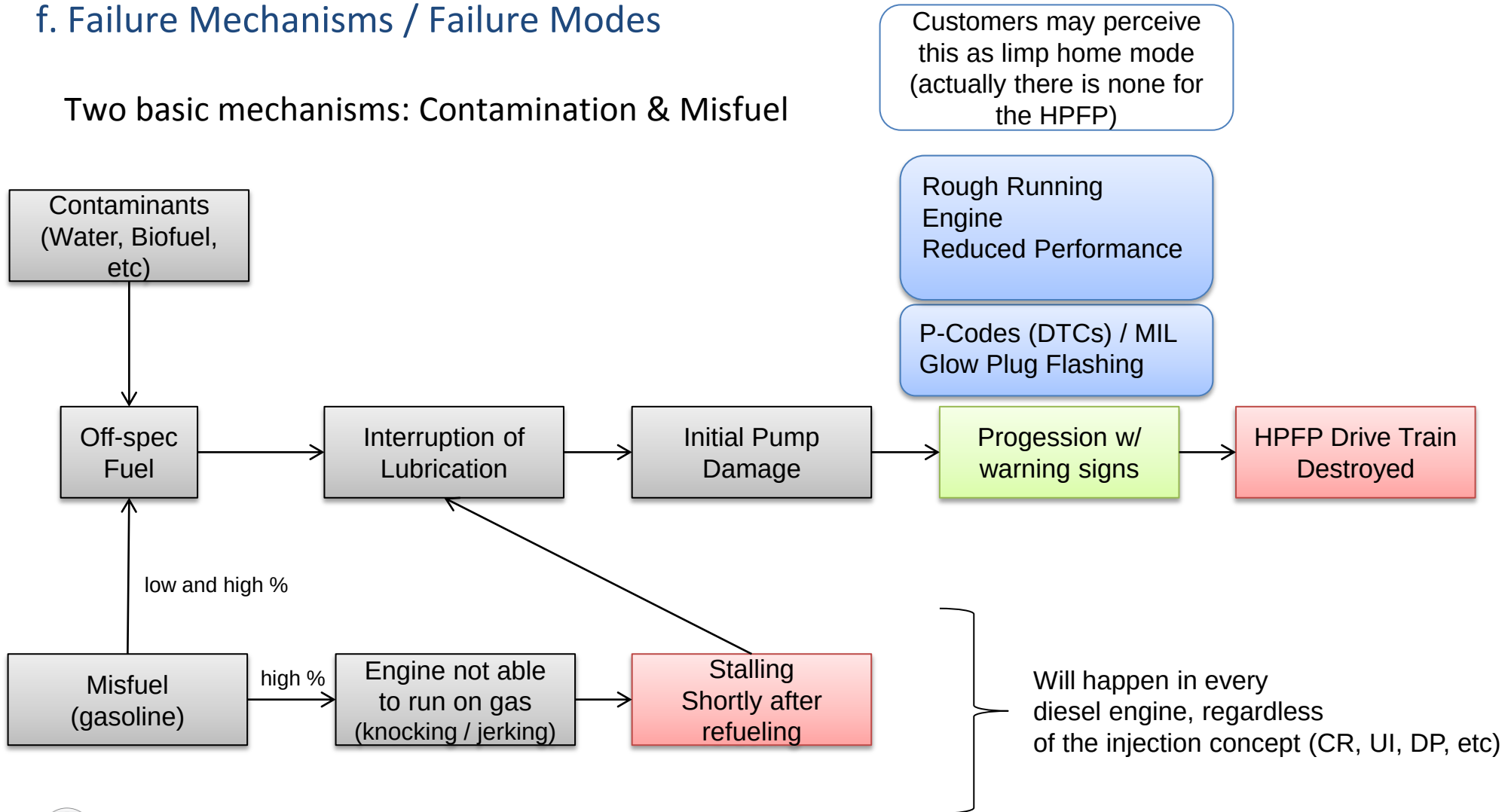


- Bosch review of 80 8D-reports
- Extensive damage to pump's drive does not always allow determination of cause
- Nearly 30% with no trouble found

4. High Pressure Fuel Pumps

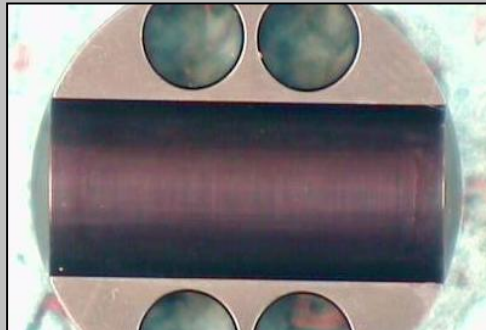
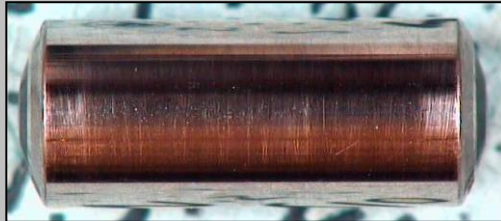
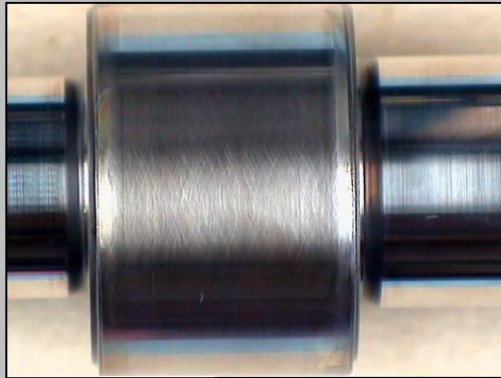
f. Failure Mechanisms / Failure Modes

Two basic mechanisms: Contamination & Misfuel

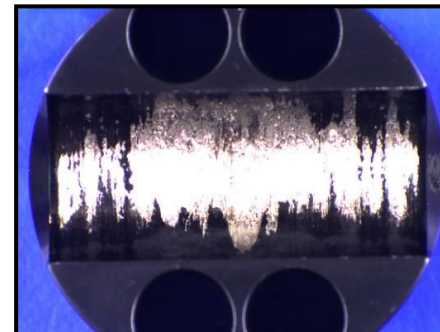
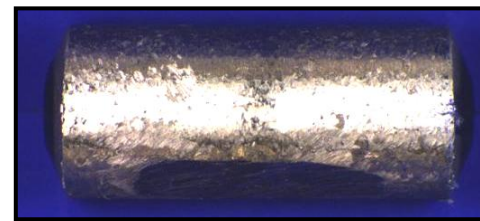
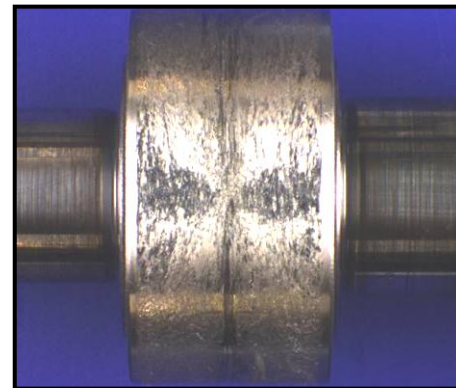


4. High Pressure Fuel Pumps

f. Consequence of Insufficient Lubrication



Normal Condition



Worn Surfaces

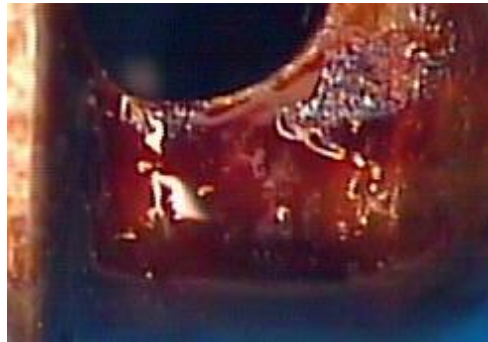
4. High Pressure Fuel Pumps

f. Contamination Examples

- Aged Biodiesel → Causes Remnants/Coating → Interrupt lubrication or sticking roller, etc.



Intake Valve



High Pressure Piston

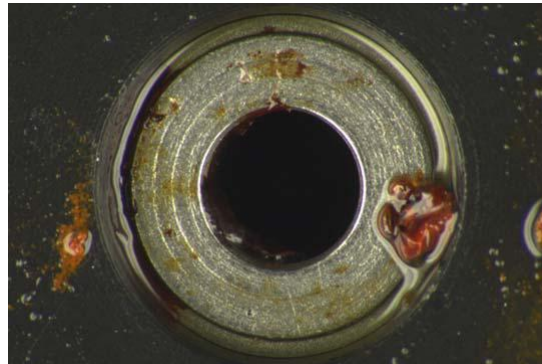


Camshaft Lobes

- Deposits / Sediments → can clog inlets and stick moving parts and cause wear



Intake Valve Inlet



Metering Unit Adjuster



Camshaft Bearing

4. High Pressure Fuel Pumps

f. Failure Mechanisms – Other Causes / Contamination

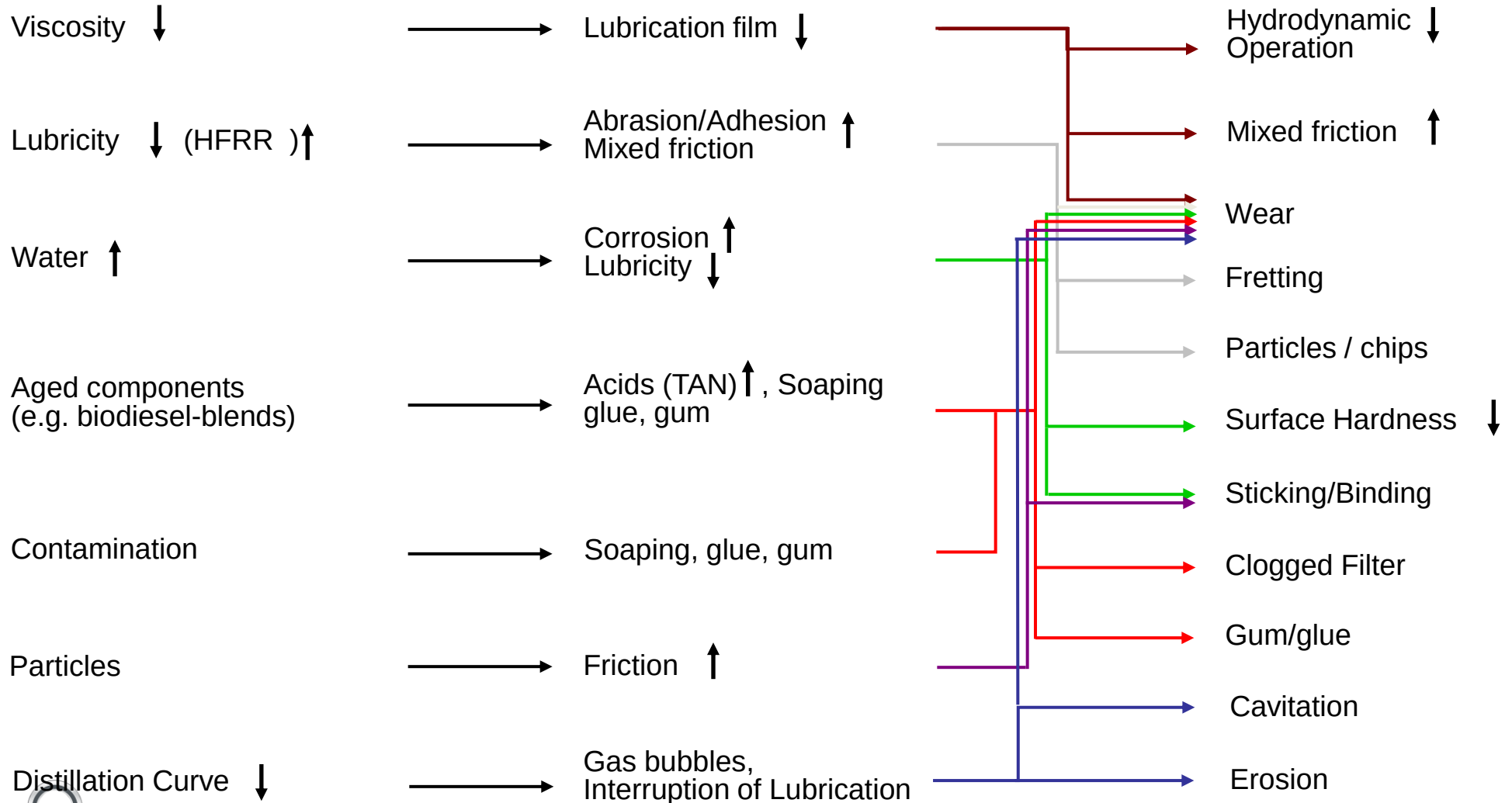
- Bad Fuel (off-spec fuel) → premature wear
- Unknown Contamination
 - Milky Fuel
 - Additives
 - Gel/gum/sludge
- Agricultural or Offroad Diesel
 - May damage pump if not according to ASTM D975 specification



Unknown Deposits, to be analysed
(Fuel filter from failed HPFP)

4. High Pressure Fuel Pumps

f. Fuel Properties – Parameters / Cause and Effect



4. High Pressure Fuel Pumps

g. Misfuel Scenarios

Standard repair manual procedures / scenarios for misfueled vehicles

- Repair manuals are provided to NHTSA (TREAD-requirement)

Scenario 1 - When vehicle was misfueled but engine has not been run

This scenario provides instructions on how to drain tank and fuel system to completely remove the wrong fuel for re-filling with correct fuel

Scenario 2 – When the vehicle was started and engine has been run

This scenario provides instructions on how to drain tank and fuel system to completely remove the wrong fuel for re-filling with correct fuel and provides instruction on how to inspect for metal shavings and about the parts that need to be replaced depending on the outcome of the inspection.

This scenario was specifically created to aid technician clean a fuel system possibly contaminated via HPFP damage

4. High Pressure Fuel Pumps

h. Running out of Fuel – Effects on HPFP

- Before the car runs out of fuel, the driver gets a (yellow) warning lamp in the instrument cluster accompanied by a chime. At this time approx. 1.8 gal of fuel remain in the fuel tank.
- If the car is driven until the fuel tank is empty, the car finally will stall after hesitation / rough running / hiccups caused by intermittent interruption of fuel supply.
- If this happens the HPFP will not actually “run-dry” as the stalling is caused by a break-down of the fuel pressure (minimum of 80-100 bar) rather than air being pumped into the HPFP.
- Running out of fuel and refilling/restarting the vehicle is part of the normal test conditions during vehicle development and may take 10 to 40 seconds. Test vehicles, which experienced “running out of fuel”, were refilled and the tests were continued. No HPFP in these tests failed at a later point of time.
- Based on this experience with test vehicles during testing and approval, the HPFP will not be damaged if the vehicle runs out of fuel



5. Conclusions

- Volkswagen has not identified a defect within the TDI Clean Diesel vehicle's high pressure fuel pump
- Volkswagen has not received any reports involving a crash, injury or fatality.
- High performance Diesel engines can only meet the environmental requirements/standards using a high injection pressure common rail approach.
- Also because of the emission requirements the HPFP must be lubricated by the fuel as communication between engine oil and diesel fuel cannot be tolerated (excluding engine oil as lubricant) and no seal/gasket could withstand the system's pressure gradients
- All current high pressure diesel fuel pumps for passenger vehicles work with fuel as a lubricant
- Volkswagen's fuel pump design is state of the art; earlier injection system designs would not be able to meet current and future requirements in regard of emissions, fuel efficiency, CO2 and performance

5. Conclusions

- If the tank is significantly filled with the wrong fuel the vehicle will likely stall when the remaining diesel in the injection system has been consumed.
- However, this is and was common for every engine:
 - No diesel (no current and no past) engine will run when filled with gasoline
 - Vice versa: No gasoline engine will run on diesel
- Fuel contamination reduces lubricity and viscosity of the fuel and can lead to damage of the pumps surfaces and lead to damage to the pump. Proper lubrication is the core element for the pump's durability
- After a certain damage progression, the pump can ultimately fail and lead to an engine stalling – typically accompanied by notice or warning to the driver like rough running engine, warning light illumination (glow plug light and MIL), reduced power/limp home.

5. Conclusions

- Field data shows a peak of incidents immediately after PE opening resume was published
- Field data shows downward trends after this – while vehicle population steadily grows
- Perhaps the media coverage led to greater awareness of „misfueling“ and consequences
- Patterns observed are not consistent with durability/aging/wear mechanisms
- The data shows a random failure pattern
- Robustness measures, implemented for other reasons, have no effect on the failure pattern under investigation (misfueling with gasoline)
- High percentage of misfuels with gasoline out of the incidents in question

5. Conclusions

- Failures are induced by „single“ outside occurrences (e.g. misfueling), not by a systematic mechanism (e.g. design)
- Failure pattern is not consistent with aging/wear/durability mechanisms and pattern does not increase with vehicle mileage
- Trends are going down despite the fact that the vehicle population is steadily growing
- The HPFP was designed, tested and verified to operate on ASTM D975 diesel fuel with an additional design margin
- The HPFP is not able to run on Jet A1 / Kerosene or Gasoline
- The HPFP will tolerate off-spec fuel or gas to a certain amount, but not a combination of both
- **Volkswagen has found no defect related to motor vehicle safety with relation to the fuel system at issue in this investigation.**