Noria's 13th Annual Conference & Exhibition
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Quick Facts for Class 8 Trucks:

- 2.4 million (excluding government and farm) in 2008 in the US alone
- There are between 35-58 quarts of oil compared to the 5-7 quarts in a typical car
- Standard oil drain interval is 25,000 miles
- One quart of 15W-40 mineral oil can cost about $3-5
- Class 8 trucks with a trailer average is just under 6 MPG, compared to 4 MPG 30 years ago

Optimizing the Oil Drain Interval (ODI) for Diesel Engines

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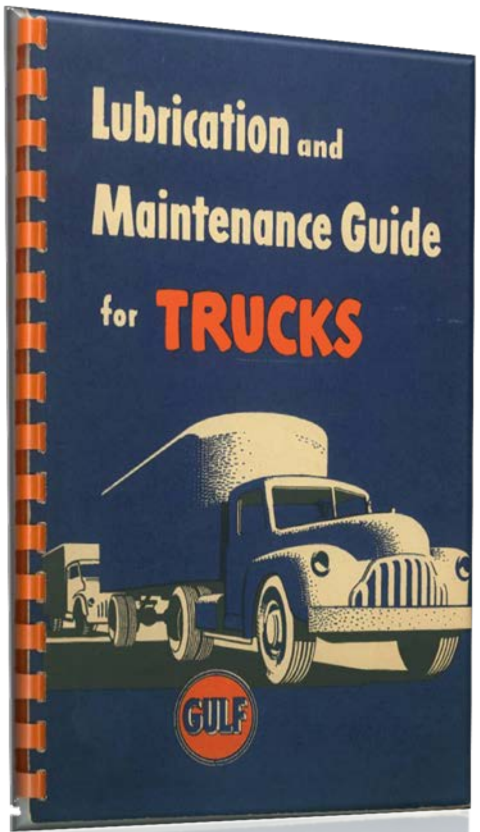
*This PowerPoint is not Navistar affiliated and should not be used as a reflection of Navistar's position on this topic.

Overview of presentation

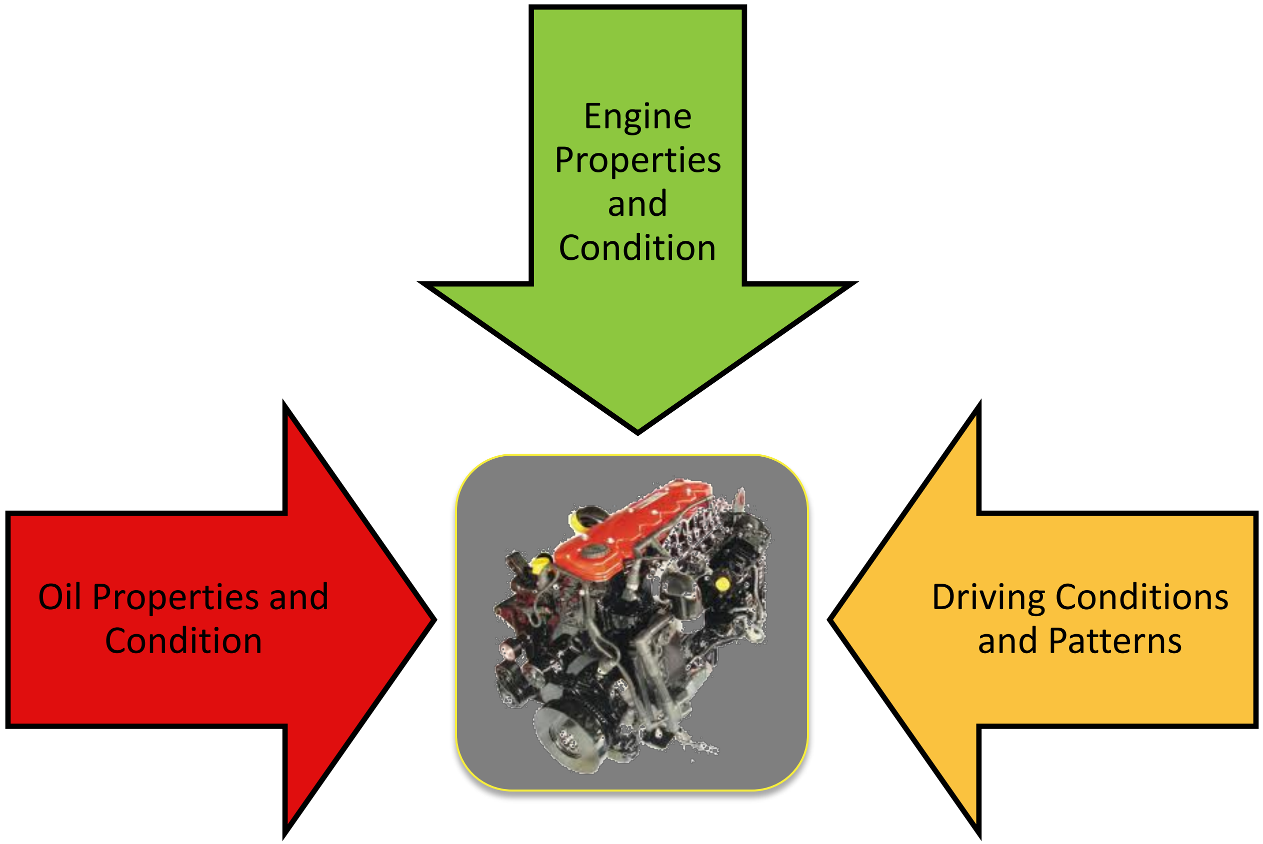
- Historical Perspective
- Quick Basics
  - How the engine is effected by degraded engine oil
  - How the engine oil becomes degraded
- Root Cause
  - Root Cause Flow Chart
  - Oil Conditions
  - Driving Conditions
  - Engine Conditions
- The Answers
  - Oil Analysis
  - Calibration and Algorithms
- Going Further
- In Review
- Acknowledgements

Historical Perspective



- The trucking industry has come a long way.
- Going back to 1949, Gulf had an oil drain interval recommendation between 500 and 1000 miles.
- This oil drain interval, with vast improvements in truck design and oil formulation, has increased to as much as 50,000 miles today.
- Crude oil prices are still driving us to reduce costs wherever possible, and improvements <u>can</u> be made.

The Factors that Induce Engine Wear and Failure



The Engine Properties that can Affect Engine Oil Life

Engine Design Efficiency

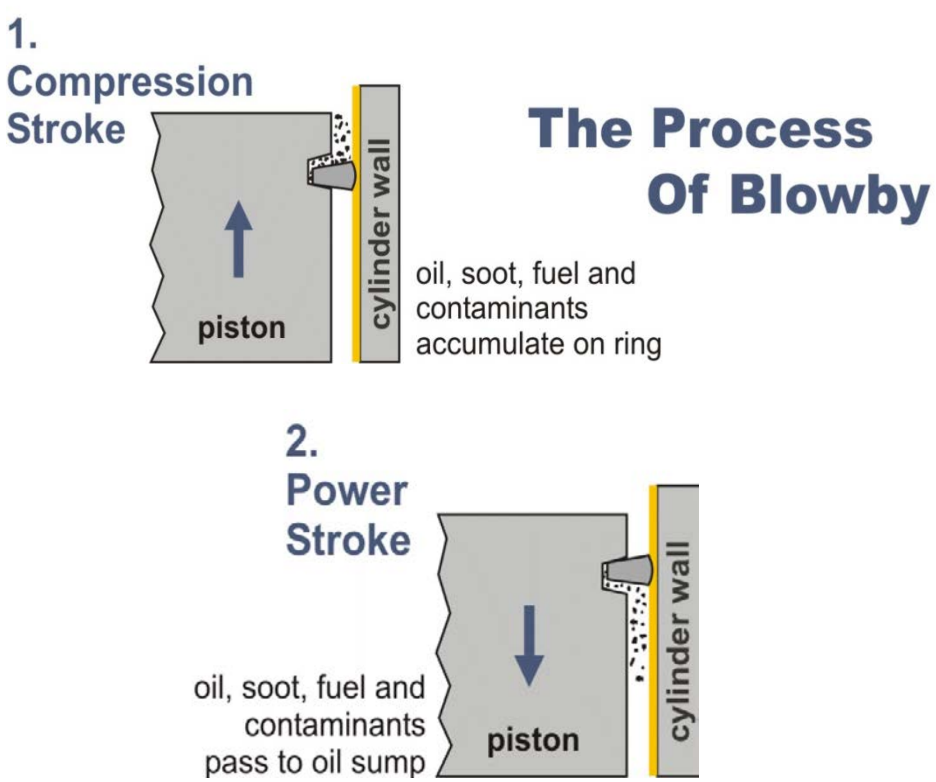
- Combustion Efficiency
- Inefficient Seal Designs
- Heat

Exhaust Back Pressure / EGR

- Pressure on piston seals
- Concentrations of NOx, Soot, and other particles in combustion chamber

Oil Capacity and Flow Rates

- Oil Filter Efficiency
- Oil Sump Size



Img ref: Noria Corp.

The Driving Conditions that can Affect Engine Oil Life

Miles Per Gallon

- Driving patterns
- Routes (city, highway, mountains)
- High loads, altitudes

Extreme Temperatures

- Cold start conditions
- Hot ambient conditions (+90˚F)

Extreme Environments

- Dirt roads, construction sites causing more opportunities for contaminant ingression
- High air humidity
- Extended Idling

Img: International WorkStar

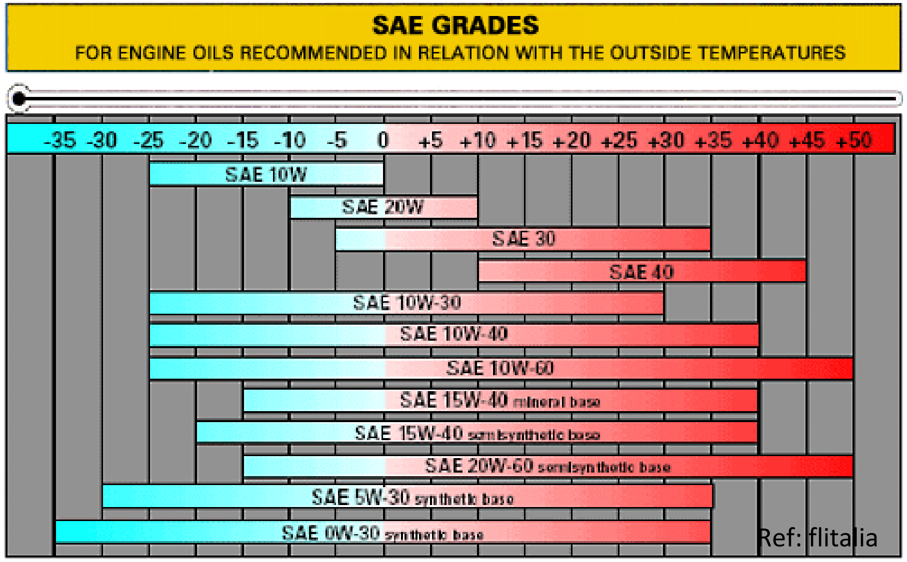
The Oil Conditions that can Affect Engine Oil Life

Contaminants

- Soot and sludge deposits can prevent the piston ring from flexing (carbon jacking), forcing more friction and wear
- Solid contaminants increase friction and wear between moving parts
- Moisture, glycol and acids promote corrosion, additive depletion, and oil oxidation
- Fuel dilution thins oil films and encourages oxidation

Defective or Incorrect Oil

- Incorrect engine oil used can prevent the oil from functioning effectively at extreme temperatures (cold or hot)
- Impaired performance from additives
- The quality of an engine oil with specific additives is a major contributor to it’s TBN (protection from corrosion)



Ref: flitalia

How Degraded Engine Oil can Kill an Engine

Internal Corrosive Attacks

- Oxidation
- Additive depletion
- Hydrolysis
- Heat

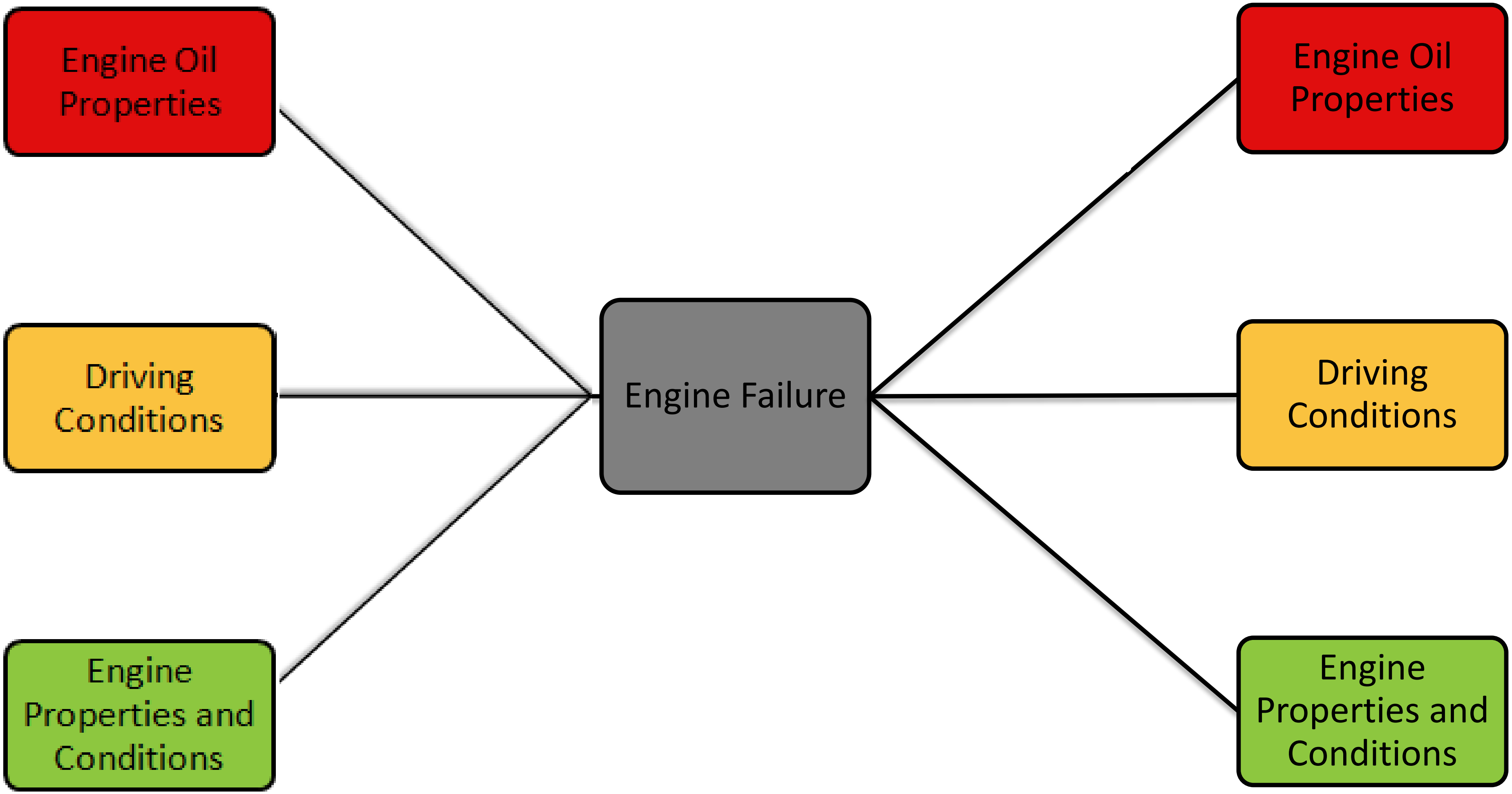
Engine Wear

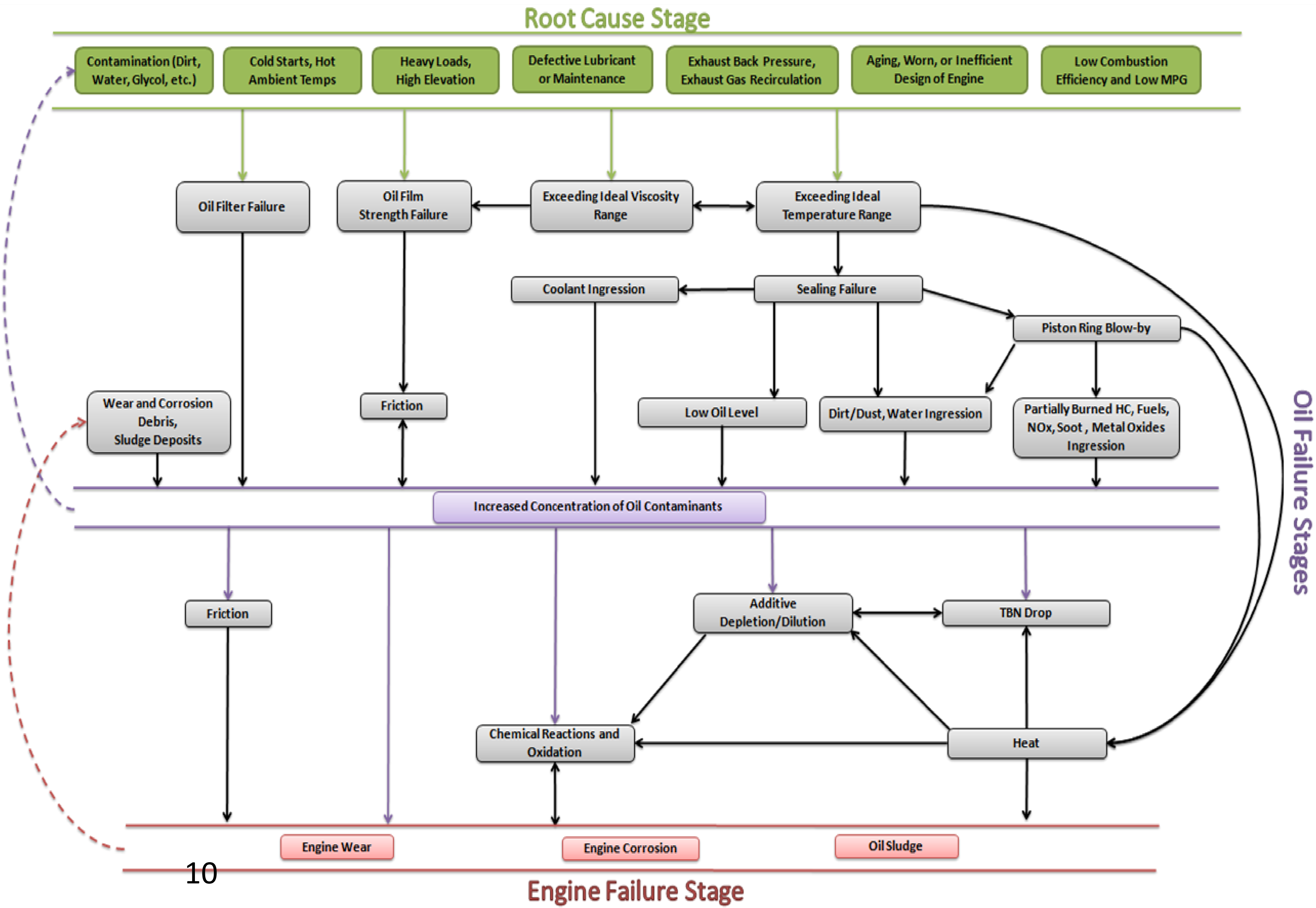
- Friction from particle contamination
- Friction from internal components due to a lack of lubrication

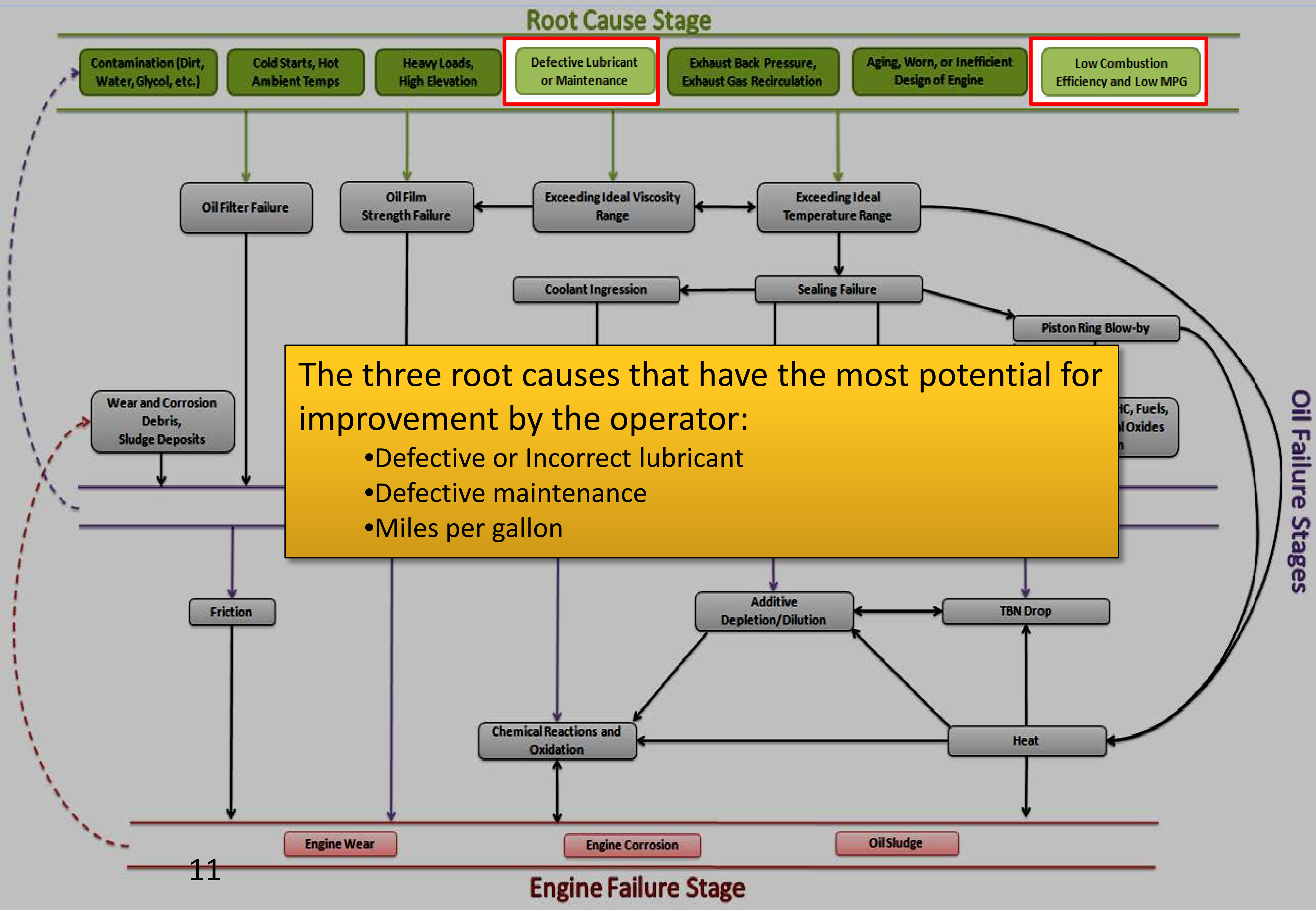
Oil Sludge (Black Death)

- Contaminants (soot, oxides, solids)
- Water and acids
- Higher Combustion Temperatures
- Additive depletion

Root Cause:


Engine Oil Properties
Driving Conditions
Engine Properties and Conditions
Engine Failure
Engine Oil Properties
Driving Conditions
Engine Properties and Conditions


Root Cause Stage
Contamination (Dirt, Water, Glycol, etc.)
Cold Starts, Hot Ambient Temps
Heavy Loads, High Elevation
Defective Lubricant or Maintenance
Exhaust Back Pressure, Exhaust Gas Recirculation
Aging, Worn, or Inefficient Design of Engine
Low Combustion Efficiency and Low MPG
Oil Filter Failure
Oil Film Strength Failure
Exceeding Ideal Viscosity Range
Exceeding Ideal Temperature Range
Coolant Ingression
Sealing Failure
Piston Ring Blow-by
Wear and Corrosion Debris, Sludge Deposits
Friction
Low Oil Level
Dirt/Dust, Water Ingression
Partially Burned HC, Fuels, NOx, Soot, Metal Oxides Ingression
Increased Concentration of Oil Contaminants
Oil Failure Stages
Friction
Additive Depletion/Dilution
TBN Drop
Chemical Reactions and Oxidation
Heat
Engine Wear
Engine Corrosion
Oil Sludge
Engine Failure Stage



The three root causes that have the most potential for improvement by the operator:

- Defective or Incorrect lubricant
- Defective maintenance
- Miles per gallon

Driving Conditions

- Driving conditions can be catalysts to impaired oil and engine conditions. But it should be emphasized that it can directly influence the extension or reduction of the oil drain interval.

  – Driving conditions include two things:
    - Where you drive
    - How you drive

Heavy Duty Engine OEM Recommendations for ODI

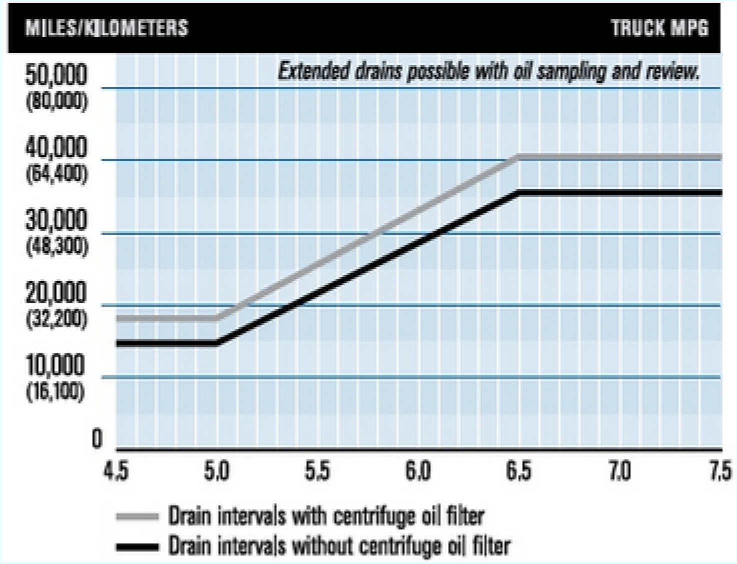
Engine		ODI						ODI Classification			
Make	Model	Light*	Medium*	Severe*	Extreme*	Oil Cap. (Qts)	HP	*Light	*Medium	*Severe	*Extreme
Cummins	ISX12	35,000	25,000	15,000		44	310-425	>6 MPG	5-6.5 MPG	<5 MPG	
	ISX15	35,000	25,000	15,000		56	400-600				
Detroit Diesel	DD13	50,000	35,000	25,000		42	350-470	>6 MPG	5-6 MPG	<5 MPG	
	DD15	50,000	35,000	25,000			455-560	>6 MPG	5-6 MPG	<5 MPG	
	DD16	50,000	35,000	25,000		47	475-600	>6 MPG	5-6 MPG	<5 MPG	
Volvo	D11	up to 35,000				38	325-405	>6 MPG	>4.7 MPG	>3.7 MPG	
	D13	up to 35,000				38	375-500	>6 MPG	>4.7 MPG	>3.7 MPG	
	D16	up to 35,000				44	500-550	>6 MPG	>4.7 MPG	>3.7 MPG	
Mack	MP7	35,000	25,000	15,000	10,000		325-405	>6 MPG	>4.7 MPG	>3.7 MPG	>2.0 MPG
	MP8	35,000	25,000	15,000	10,000		415-505	>6 MPG	>4.7 MPG	>3.7 MPG	>2.0 MPG
	MP10	50,000	35,000	25,000	15,000		515-605	>6 MPG	>4.7 MPG	>3.7 MPG	>2.0 MPG
PACCAR	MX	up to 40,000				42	380-485				
MaxxForce	11	40,000	30,000	18,000		42	330-390	>6.5 MPG	5-6.5 MPG	<5 MPG	
	13	40,000	30,000	18,000		42	410-500	>6.5 MPG	5-6.5 MPG	<5 MPG	
	15	40,000	30,000	18,000		42	425-550	>6.5 MPG	5-6.5 MPG	<5 MPG	
CAT	C11					42	305-370				
	C13					42	305-470				
	C15					42	435-625				

2010 MaxxForce ® 11L & 13L Regional and Line Haul Vehicles ' Service Intervals *			
Operations / Fuel Economy	LIGHT= 6.5 MPG or Higher (MORE THAN 4 KmpL)	MODERATE = 6.5 mpg –5.0 mpg (3–2 KmpL)	SEVERE = LESS THAN 5.0 mpg (LESS THAN 2 KmpL)
Change Engine Oil and Filter† Part # 3007498C92	40,000 mi/64,400 km**	30,000 mi/48,300 km** (Based on a fuel economy of 5.8 mpg)	18,000 mi/29,000 km**
Change Centrifuge Filter Part # 2606467C91	With Oil Change	With Oil Change	With Oil Change

Heavy Duty International truck manuals specify that with their 2010 MaxxForce engines, if you have obtain 6.5 miles per gallon or greater then the recommended oil drain interval can be as much as 40,000 miles

This is an improvement from previous MaxxForce engines that specified a 25,000 miles oil drain interval.

Drain Interval for Regional and Line Haul, Based on MPG



Ref: MaxxForce Service Manual

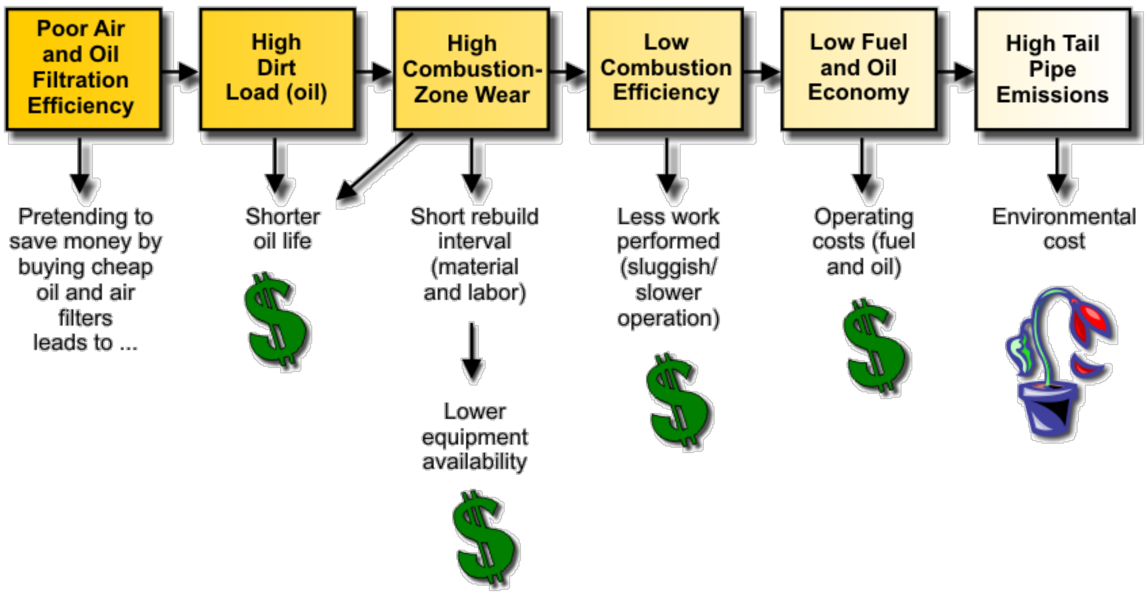
Sealing Challenges

- There are a few challenges engine oil faces that are the unpredictable factors to when and where it will cause engine failure
  - Coolant Contamination
    - Glycol and Water
      - Leads to oxidation, corrosion, additive distress, loss of dispersancy, premature filter failure.
      - Just 0.4 percent coolant containing glycol in diesel engine oil is enough to coagulate soot lead to sludge, deposits, oil flow restrictions and filter blockage.
  - Piston Blow-by
    - Fuel Dilution
      - Contains unsaturated aromatic molecules that are pro-oxidant leading to TBN drop and the eventual engine corrosion.
      - Decrease in Viscosity
    - Soot
      - Can lead to an increase in viscosity and many other issues.

Ref: Noria Corp

Every Engine is a Little Different

- Factors among different engines that affect the ODI:
  - Age of the engine
  - Miles on engine
  - Engine design
    - Exhaust gas recirculation
    - Aftertreatment system
    - Filter options (oil, fuel, and air)



Ref: Noria Corp

When to choose a better filter

- Several commercial filters are available to improve the life of the engine oil.
  - One example: WIX XD
    - Designed for high capacity and high efficiency
    - Spin-Flow Technology
      - Nylon fins that spin the incoming contaminated oil in a clockwise, centrifugal flow to help disperse heavy contaminants
  - It is key to ensure that the filter choice has the dirt-holding capacity in-line with the oil change interval.
  - Make sure filters are tested to ISO 4548-12 related to capture efficiency (micron rating) and dirt-holding capacity.

<u>Good rule of thumb when choosing a filter:</u>
Quality of filter should correlate with quality of engine oil
You get what you pay for

Engine Factors that Lead to Shortened ODI

- More stringent emissions strategies
- Engines with smaller oil capacities increase the concentration of contaminants, thus decreasing the ODI
  - 13L 2010 MaxxForce Engine – 42 quart capacity
  - Detroit Diesel DD13 – 42 quart capacity
  - Volvo D13 – 38 quart capacity
  - Cummins ISX 12 – 44 quart capacity
- Also engines that have difficulty maintaining a proper oil level can increase the concentration of contaminants as well as heat thus causing further damage to the engine.

Engines with a strong history of failure cannot be reliable candidates for extended oil drain intervals.

Major Engine Oil Properties

Property	Contributed by		
	Base Oil Mineral	Base Oil Synthetic	Additives
Viscosity	H	H	L
Viscosity/temperature (IV)	M	H	H
Shear Stability	NE	NE	H *
Anti-Wear protection	L	M	H
Rust & Corrosion Protection	NE	NE	H
Oxidation Stability	M	H	H
Low Volatility	M	H	NE
Thermal Stability	M	H	M
Low Temperature Pumpability	L	H	H
Additive Solubility	NE	H *	NE
Low Cost	L	H *	H *
Detergency	L	L	H
Soot Control (Dispersancy)	L	M	H

NE - No Effect

L - Low (minimmum)

M - Medium

H - High

* Negative Effect

Ref: Shell Synthetic Oil White Paper

Advertised Advantages of Premium Engine Oils
(typically with synthetic basestocks)

Improved fuel economy

- reducing operating costs
- This is only correlated with the lower viscosity of synthetics.

Improved oil pumping on low temperature start-up

- reducing wear

Improved startability

- reduced starting times

Improved engine cleanliness

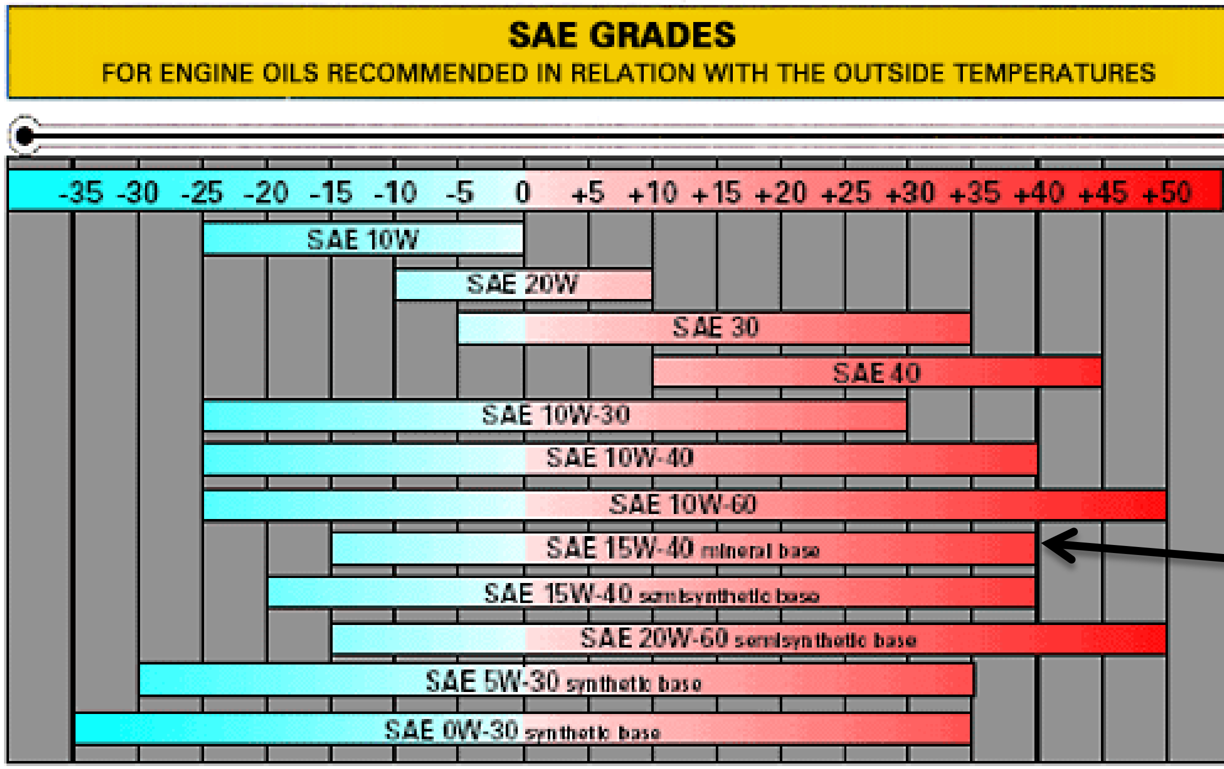
- resulting in maintenance of engine performance (emissions, fuel economy etc) throughout the oil drain interval

Improved soot handling

- Prevent sludge formation and oil way blockage in modern emission controlled engines

Ref: Shell Synthetic Oil White Paper

use



Longtime Industry Standard

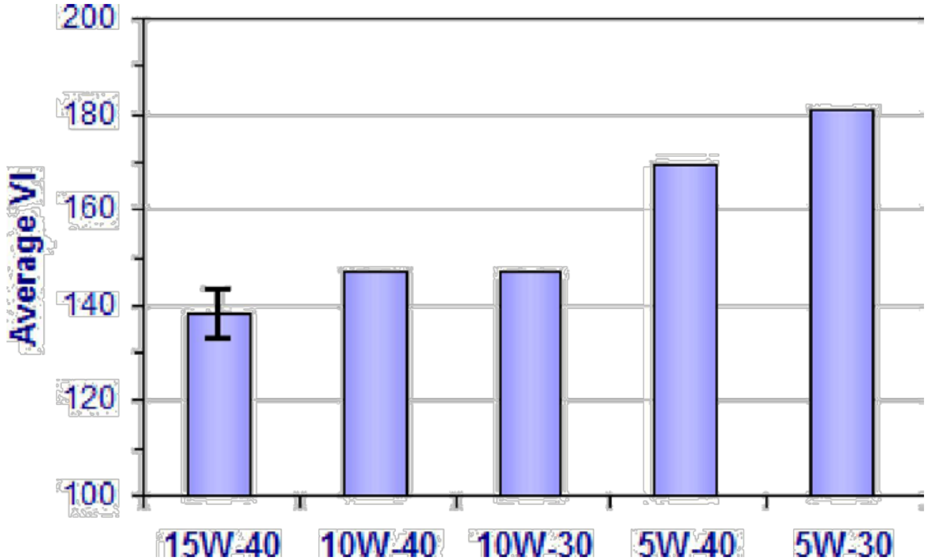
Improvement possibilities with10W-30 or 5W-30 Synthetics

- Possible fuel economy improvements as viscosity is decreased
- Must meet API-CJ4 requirements
- 5W-30 ambient temperature range no greater than 90 ˚F is disadvantageous

Ref: *flitalia, dieselnet.com*

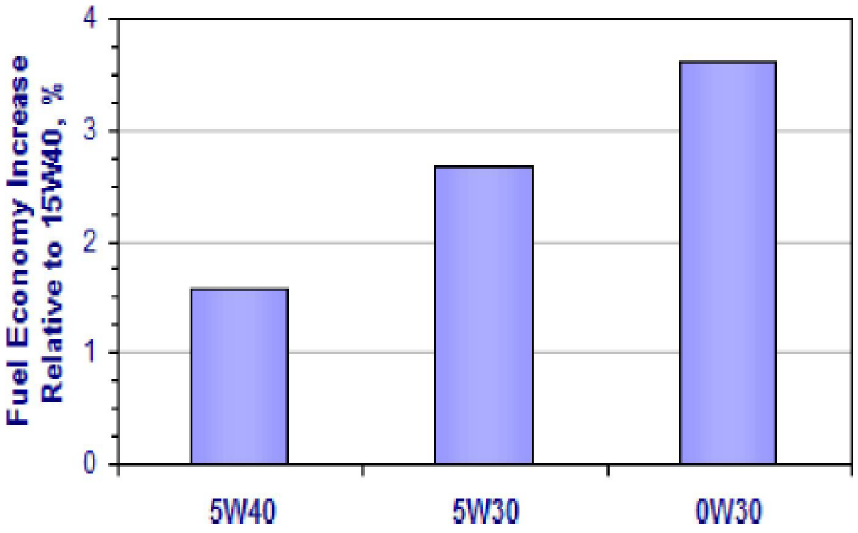
Impact of Average Viscosity Index on HTHS

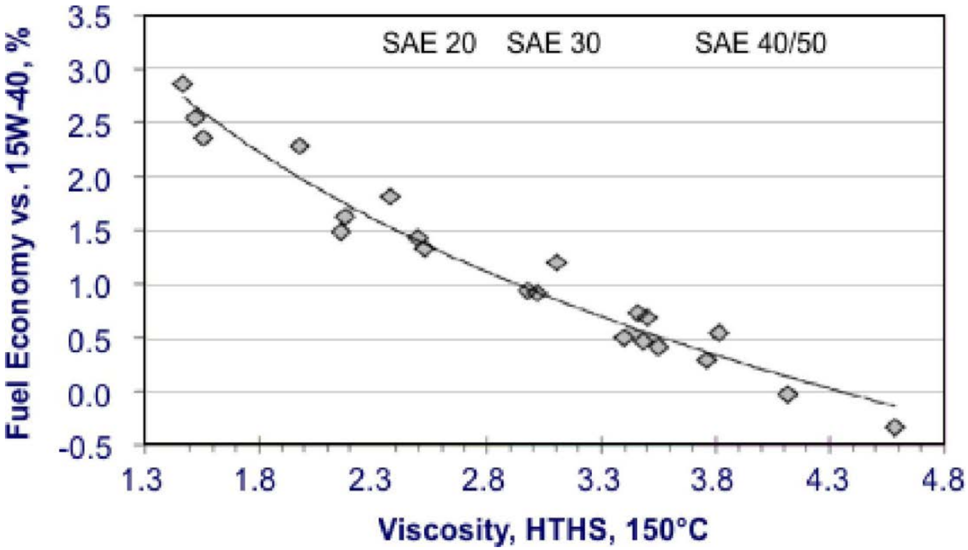
- With increasing pressure to improve today's fuel economy, lower viscosity grades are becoming more desirable.
- With heavy duty engines, a better protection against high-shear-rate is necessary compared to lighter duty vehicles.
- API CJ-4 requires a minimum high temperature high shear (HTHS) viscosity of 3.5 cP. Too low HTHS viscosity adversely affects protection of bearings and ring (cylinder wall contacts). Too high HTHS viscosity adversely affects fuel economy.
- Higher average viscosity index assists in maintaining a proper HTHS of 3.5+ mPa*s for heavy duty vehicles.



Ref: *dieselnet.com*

Impact of Average Viscosity Index on HTHS





- SAE 5W-30 (Shell Rimula R6 LME) has been measured to have a 1.1% lower fuel consumption compared to 10W-30 in a Scania DC9 with a EURO III engine.

Ref: Hausbuerger 2007 , Shank 2011

dieselnet.com

The Million Dollar Question

- When does the cost saved by extending the oil drain interval become insignificant compared to eventual damage costs from extending this interval?
  - If the oil could talk, it would say...
    - When any oil attributes degrades to it's condemning limit
    - When the loss of TBN leads to internal corrosive attacks
    - When sludge begins to build up and lodge itself onto engine components

The answer lies with the operators ability to monitor the quality of the oil at any given moment either by

- Oil analysis
- Estimating based on driving routes, driving styles, environment, engine oil in use, and the current condition of the engine.

Extended ODI Oil Analysis Criteria

- Oil sample collection methods must follow a proper sampling procedure
  - Consistent intervals, at least 10,000-15,000 mile interval is acceptable
  - Thorough records of mph, mpg, date, oil used, maintenance logs, make-up oil volume during interval, driving patterns, idling time, engine history.
  - An appropriate and consistent sampling port use
  - An appropriate consistent testing method

Oil Analysis Guidelines for Cummins Engines

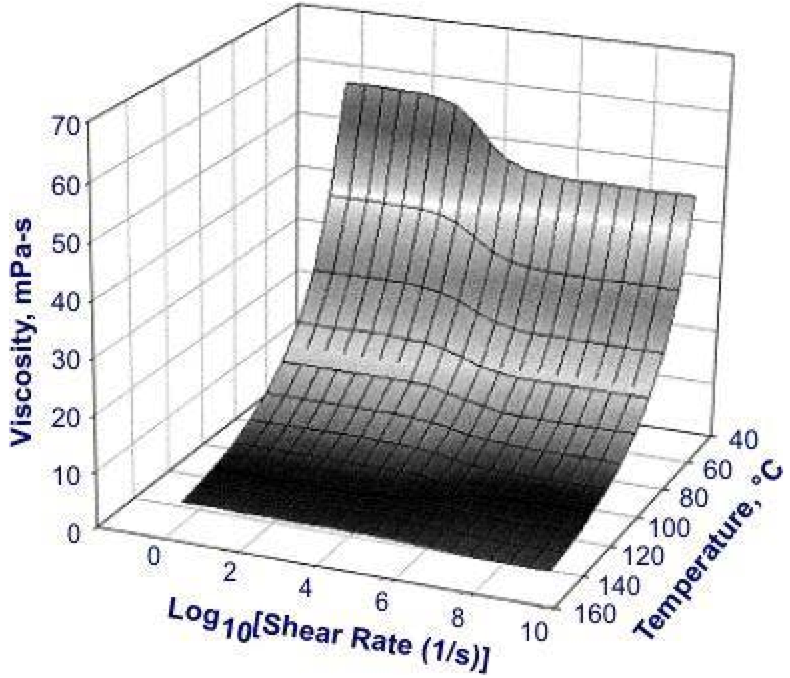
*Cummins Note: These contamination guidelines are guidelines **only** (and considered to be loose by many). This does **not** mean values that fall on the acceptable side of these guidelines can be interpreted as indicating the oil is suitable for further service.*

Property	General Guideline
Viscosity change @ 100°C (ASTM-D445)	±1 SAE Viscosity grade or 5 cSt from the new oil
Fuel Dilution	5 %
Total base number (TBN) (ASTM D-4739)	2.5 number minimum or half new oil value or equal to TAN
Water content ASTM (D-95)	0.5 % maximum
Potential Contaminants	
Silicone (SI)	15 ppm increase over new oil
Sodium (Na)	20 ppm increase over new oil
Boron (B)	25 ppm increase over new oil
Potassium (K)	20 ppm increase over new oil
Soot (wt %)	Midrange B and C

Ref: Cummins

API CJ-4 HTHS viscosity requirements

High-Temperature High-Shear Viscosity	Covers the laboratory determination of the viscosity of engine oils	Viscosity	Viscosity @ 150 degrees C, minimum	3.5 cP

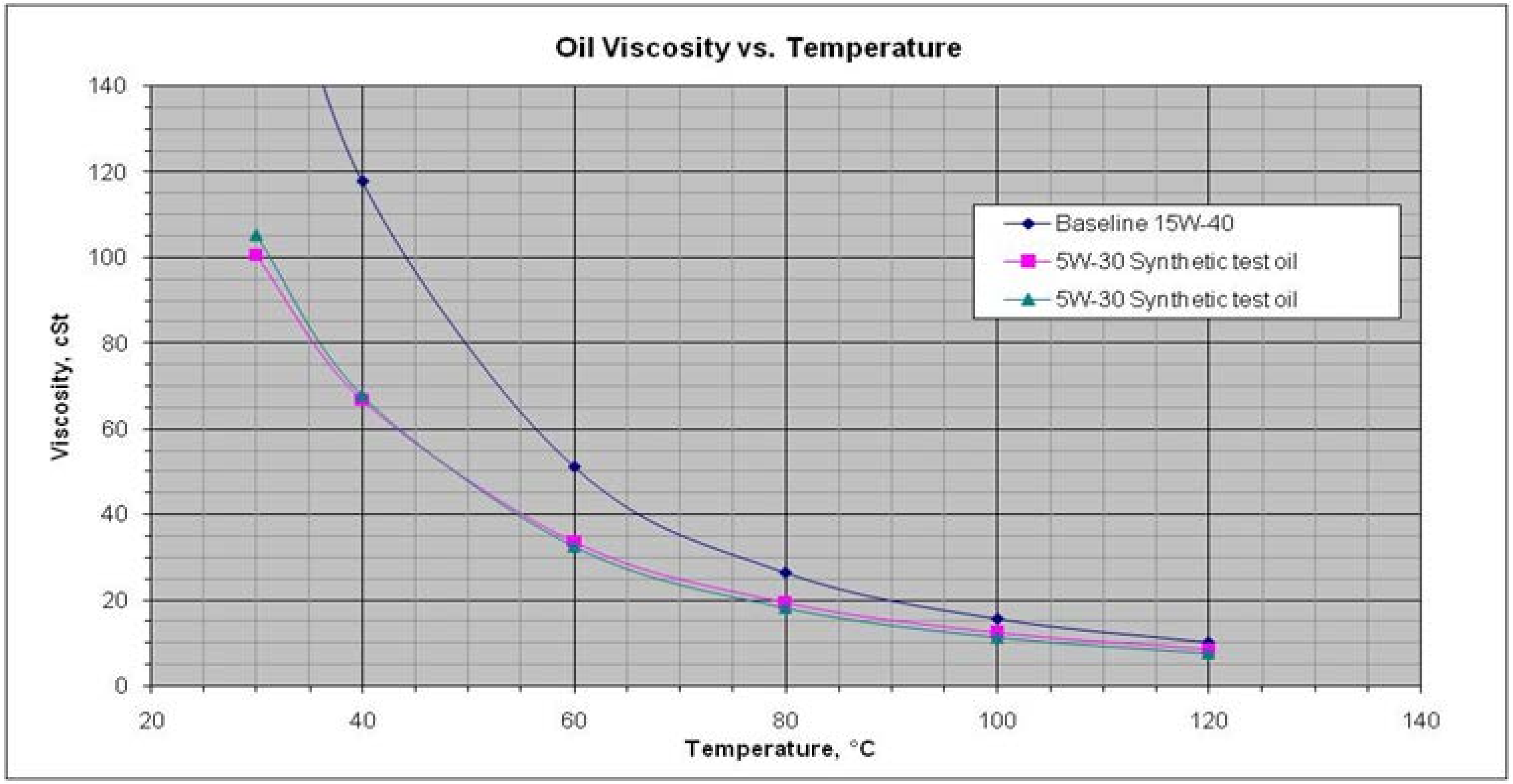


- Engine oil has a tendency to act as a Newtonian fluid at low and high shear rates but act as a non-Newtonian fluid at specific intermediate shear rates.

Ref: Taylor, R.I., Coy, R.C., 2000

dieselnet.com

Deciphering the Engine Oil Options

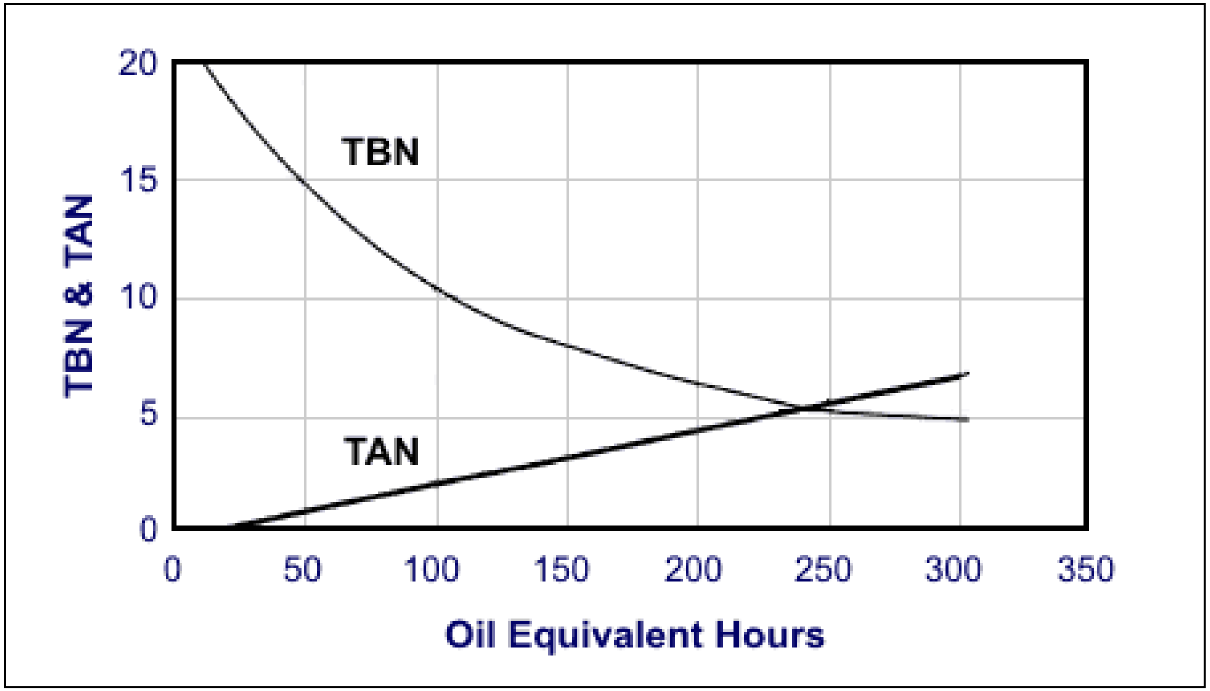


Note with friction modifiers (polymeric additive):

- They have a "shear thinning" viscosity (increase shear with decreased viscosity).
- HD Trucks do not have enough boundary lubrication to make a difference.
- Cost more

Neutralization

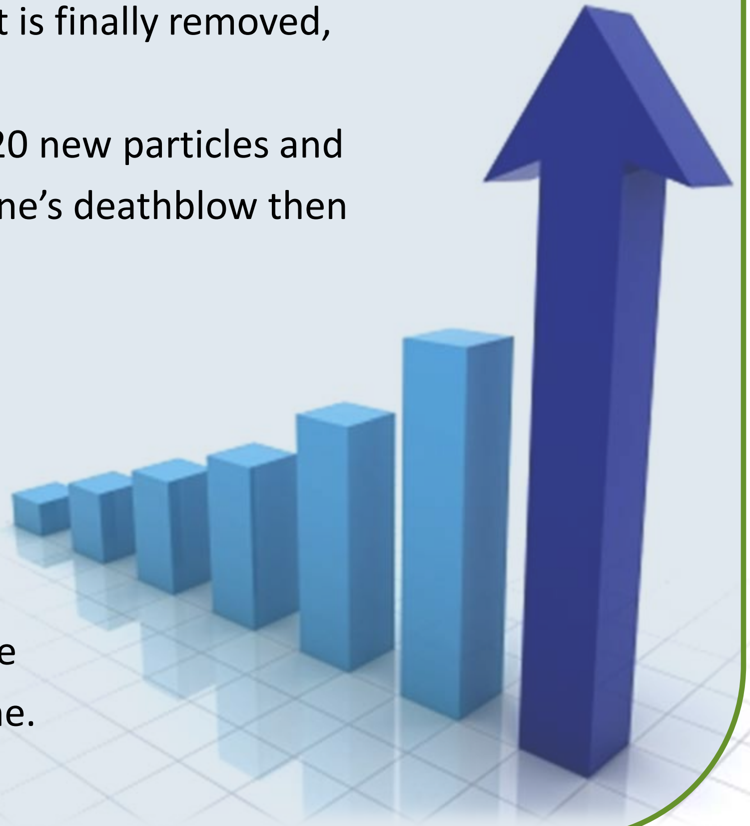
- The TBN number can act as a primary indicator of the age of the oil.
  - TBN is a good indicator to summing up the effects of contaminants on the engine oil, heat related stressors, and the engine oil's overall ability to continue functioning in a positive way.
  - When an engine oil loses its alkalinity (detergent additive) the TBN will drop (corrosion risk).
  - When an engine oil begins to oxidize or become excessively contaminated with glycol or combustion blowby acids its TBN will drop.



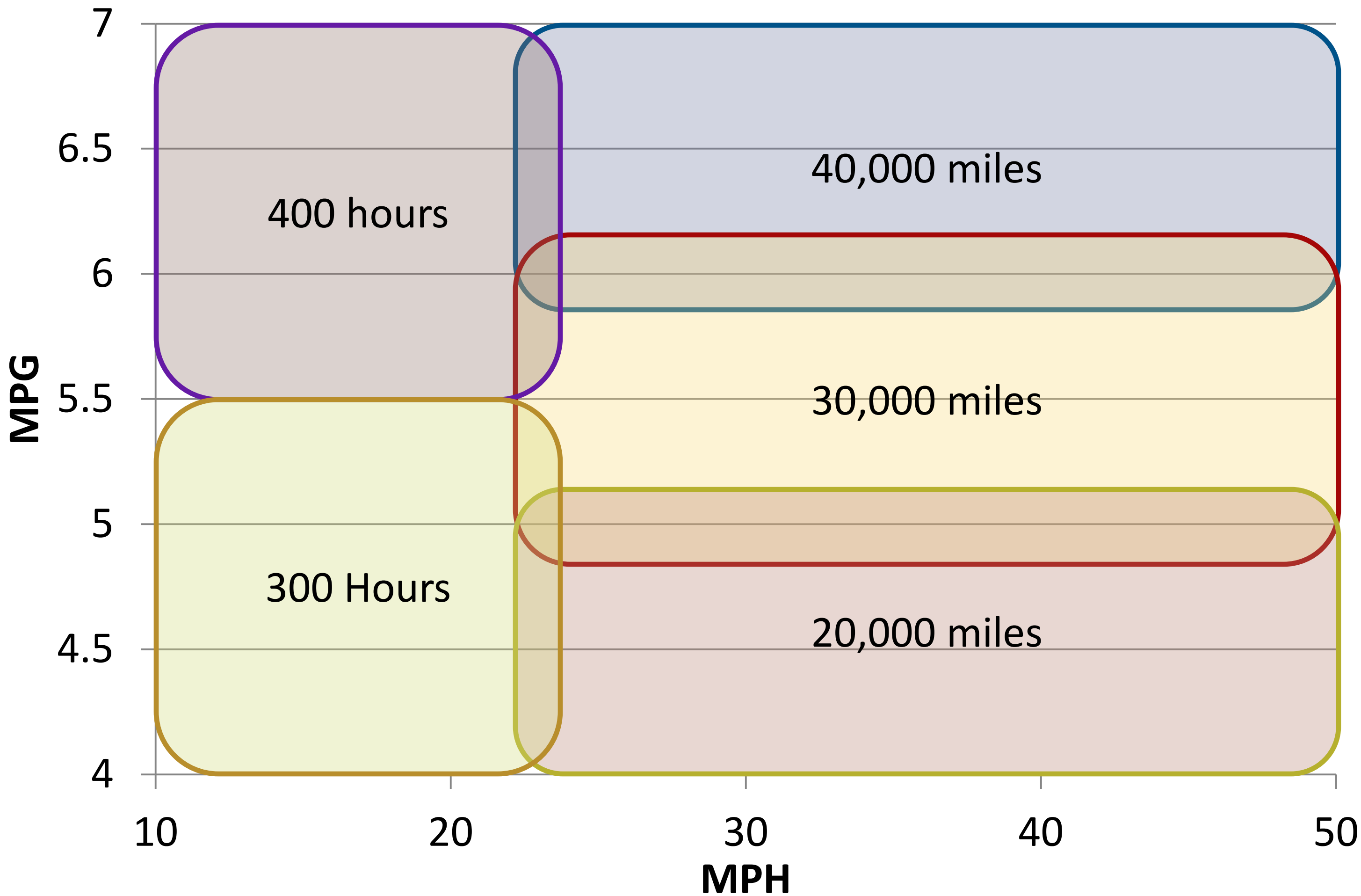
Ref: *dieselnet.com*

Particle Control

- Particles produce particles
  - One particle has the power to generate as many as 20 new particles from the time of ingression to when it is finally removed, obliterated, or settled away.
  - After simulating this same potential for these 20 new particles and so on, the oil appears to act more like the engine's deathblow then the it's lifeblood.
- Mass balance
  - The filter is essential in maintaining the ability to remove at least the same number of contaminants that are ingressed in the oil throughout the filter's life. If not, these contaminants will propagate into a engine-wide pandemic and the eventual failure of the engine.



Calibration as a Solution Method:
Fuel Econ vs. Ave. Speed Calibration Map ODI Estimations



Note: This is only an example, not based of tests

Calibration as a Solution Method: Possible Algorithms

- Three unproven methods to calculating the oil drain interval.

Paradise Garage Method:

$$\left[\left(\frac{tested\ TBN}{virgin\ TBN}\right) tested\ miles\right] + tested\ miles = oil\ change$$

Kublin Method:

$$(virgin\ TBN)(10)(oil\ capacity)\left(\frac{cubic\ inches}{horsepower}\right)(mpg) = oil\ change$$

Heidebrecht Method:

$$\frac{(total\ oil)(virgin\ TBN - target\ TBN)}{(cylinder\ bore)(\pi)(no.\ cylinders)(compression\ ratio)(neutralization)} = oil\ change$$

Ref: *oilstudy.spacebears.com*

- Simply using the known TBN of the engine oil used at the time of fill, the critical TBN limits, and the physical characteristics of the engine, a decent formula can be created to estimate the oil drain interval time.

Calibration as a Solution Method: Onboard Sensors

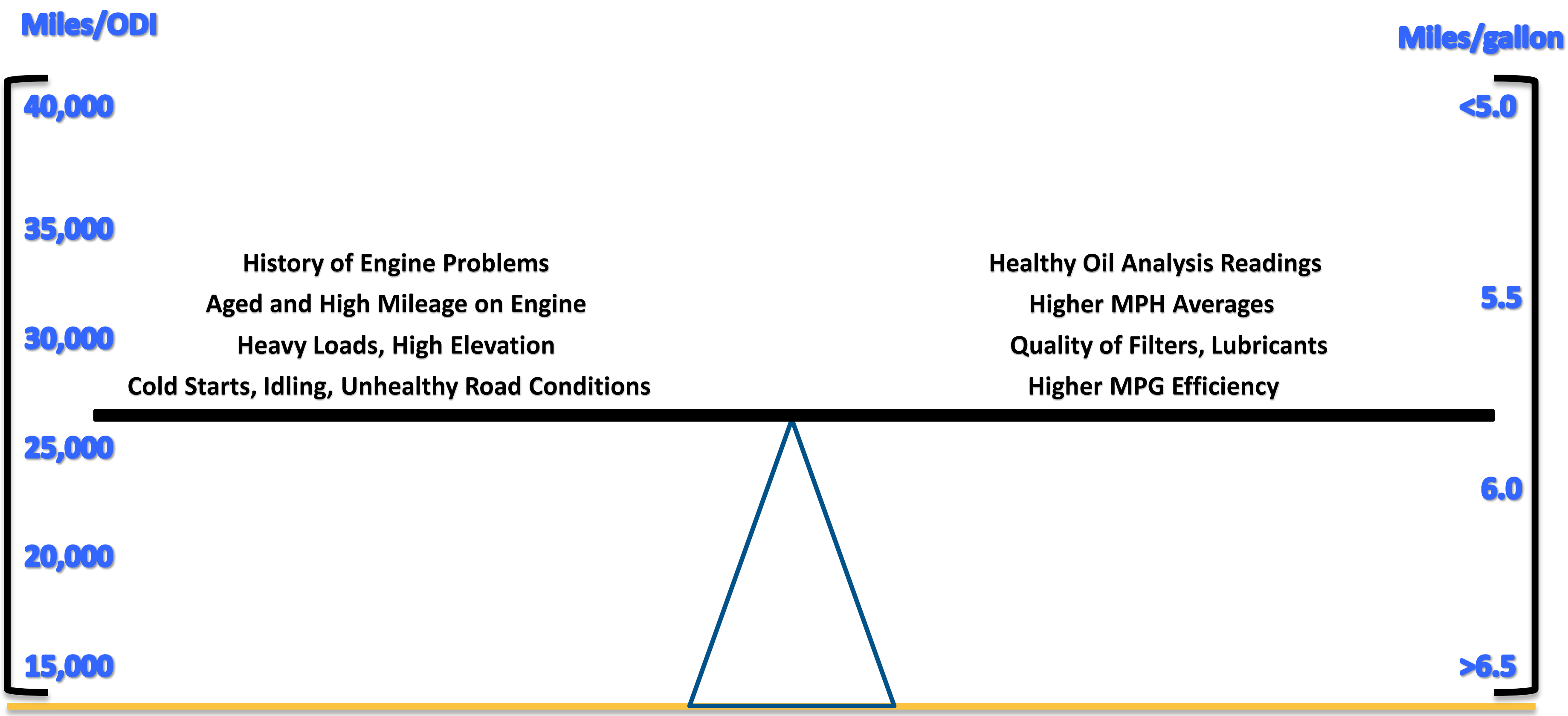
- Onboard sensors can provide significant improvements in determining a proper ODI
- Many sensors that could be useful to monitoring the oil condition are already in place such as coolant temperature, vehicle speed averages, fuel consumed, engine rpm, oil temperatures, etc.
- In addition, a sensor dedicated to monitoring the oil condition can be done through:
  - Electric capacitance or dielectric loss factor
  - Micromechanical resonator
  - Microacoustic (piezoelectric effect)
  - AC signals
  - Water and glycol contaminant levels
  - Oil levels
  - NOx levels

Ref: Noria Corp

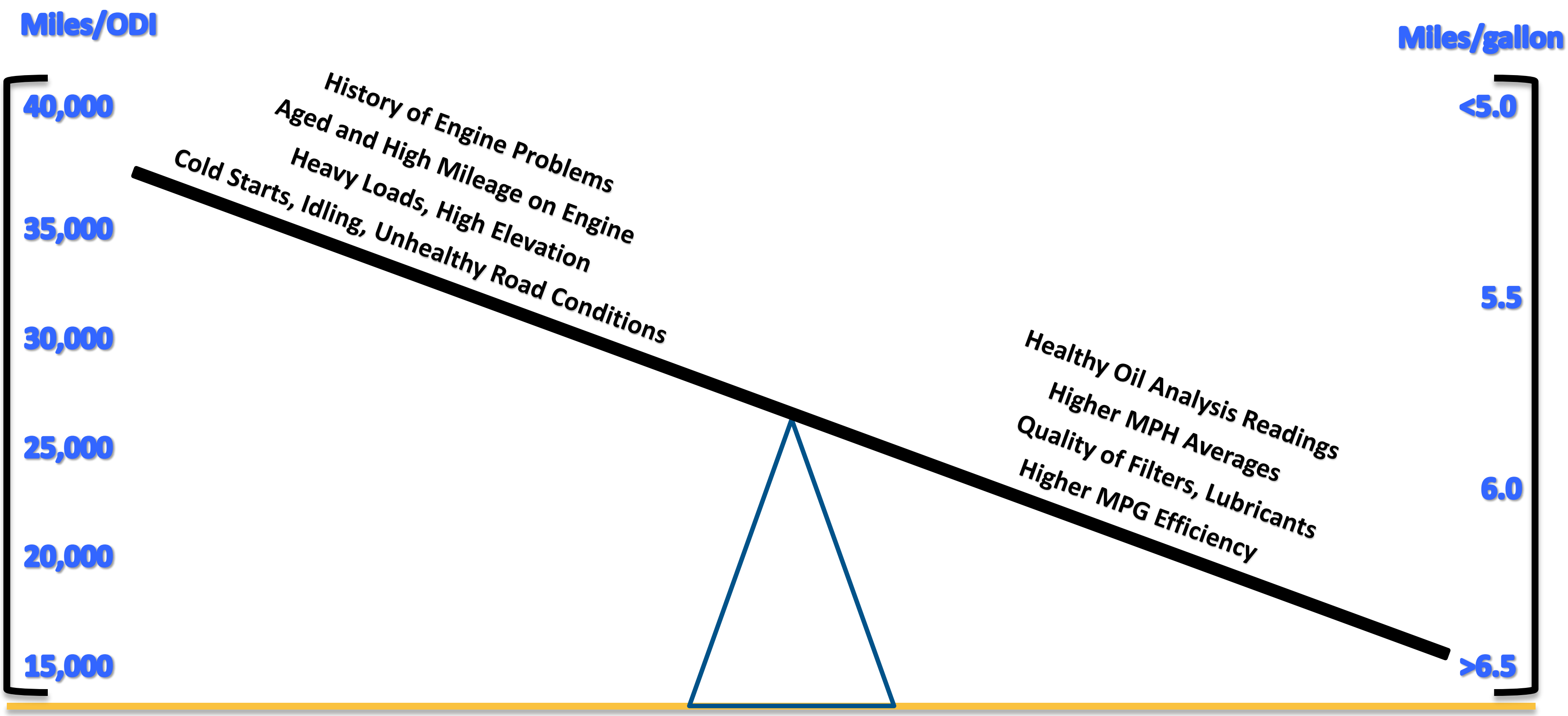
Future Opportunities

- API PC-11 (Proposed Category-11) for Diesel Engine Oil.
  - A new benchmark for heavy duty diesel engine oil to meet the increasing need to improve fuel economy through a lower viscosity oil solution, among other needed changes.
  - Creation of two sub-categories
    - Category one for backwards compatibility historical HD oils
      - Maintain a HTHS viscosity of 3.5 mPa*s
    - Category two for fuel economy improvements
      - Allowance of 2.9 mPa-s (thus having friction reduction)
      - Improved protection under higher engine operating temperatures
      - Improved protection against engine oil shear down
      - Increased wear concerns may be addressed with improved piston/liner improvements, among others.
  - Began in June 2011, first license no later than 2016

Optimizing the Interval: Weighing the Factors



Optimizing the Interval: Weighing the Factors



A Different Approach between Fleet Owners and Owner-Operators

- Fleet Owners
  - Huge potential for development of truck based and route based optimum ODI justification through oil analysis and trend analysis.
  - Keeping a close log of the results based on the driver can be an influencing factor as well.

- Owner-Operators
  - Potential for reasonable estimations due to the owner's ability to monitor and understand their own truck's tendencies and history.
  - Understanding the influencing factors such as the owner's driving style, environment, chosen engine oil and filter, and engine efficiency, etc. can provide justification to an optimal ODI.
  - Oil Analysis is still recommended if reasonably available.

In Review: Optimizing the Interval

- Oil degradation can root from engine properties, driving conditions, and characteristics of the oil itself.
- The use of synthetic oil does not automatically allow the extended ODI.
- How you drive and where you drive can significantly affect your ODI.
- Engine properties such as oil capacity, combustion efficiency, aftertreatment solution options can all affect the ODI.
- While extending oil drain intervals does save immediate costs and time, it may not be the lowest cost of ownership option depending on your circumstances.
- Extending drains can lead to higher soot and oxidation levels that increase oil viscosity, which would negatively impact fuel economy.

Ref: Heather DeBaun

In Review: Optimizing the Interval

- In many cases the optimal drain interval may not be reached prior to recommendations given by the OEM.
- TBN can be a good measure of the quality of the oil and when it's reached it's condemning limit.
- Using oil analysis or smart estimations based on all the known factors can be effective in providing a good ODI to follow.
- Potential for a onboard calibrated solution in adoption with current and/or added onboard sensors to provide a highly effective solution to "flexible" oil drain interval.

Thanks and Questions

- Any Questions?