



CITGO Pacemaker Gas Engine Oil

The webinar will begin in less than 10 minutes.

Abdul Maye



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The webinar will begin in less than 5 minutes.

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CITGO Pacemaker Gas Engine Oil

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Abdul Maye

- **CITGO Sr. Product Specialist**
- **BS, Chemistry**
- **15 Years Experience in Lubricants**
- **STLE Certified**
 - **Oil Monitoring Analyst I**





Gas Engine Oil

North American Market

- Core Consumers
- Major OEMs

Gas Engine Oil Basics

- Contrast with HDEO
- Four-Stroke
- Two-Stroke

Important Lubricant-related Issues

CITGO NGENO Product Line

CITGO LubeAlert

NGEO Market



Well Head Gas

Gas Gathering



**Main Gas
Transmission Lines**



**Landfill Gas,
Digester or CHP**



NGEO Application – Wellhead to Consumers

Application

Wellhead Gathering

Gas Processing Plants

Pipeline Compressor Stations

Industrial Power Plants

Bio Gas / Landfill

Typical Natural Gas Engine Types

Small 4-Stroke, Small 2-Stroke

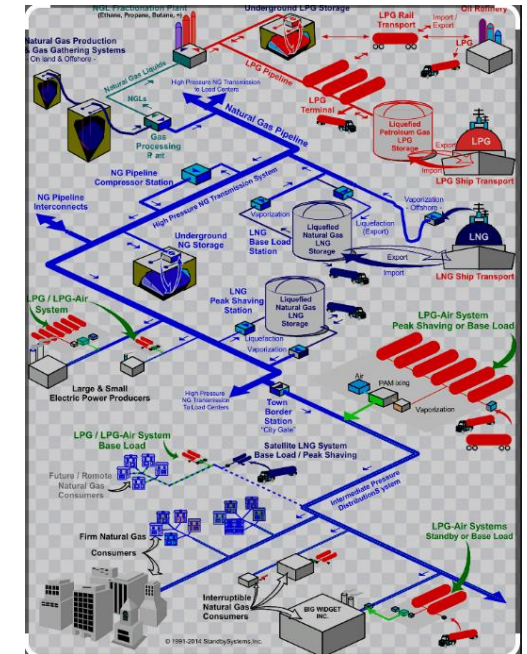
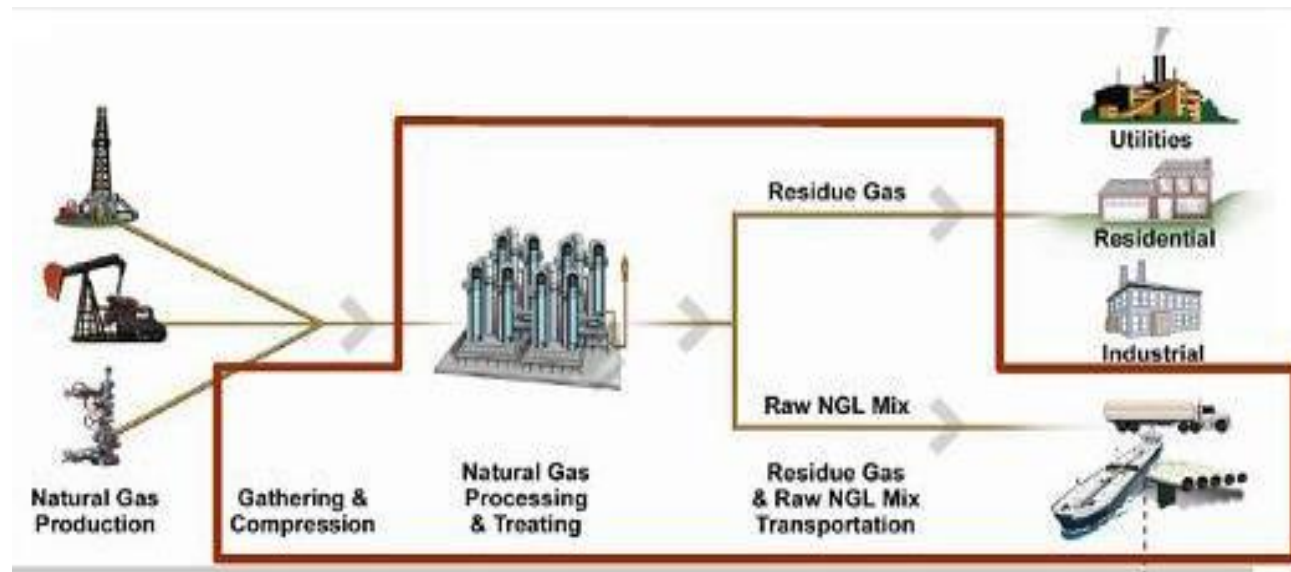
Large 4-Stroke

Large 2-Stroke, Large 4-Stroke

4-Stroke, Co-Generation

(CHP – combined heat and power)

Large 4-Stroke



Natural Gas Engine Users

- **Oil & Gas Industry – 80%**
 - Natural Gas Transmission & Gathering
 - Oil Well Pumping
- **Agricultural Industry – 10%**
 - Irrigation Pumping
 - Dairies
- **Commercial – 5%**
 - Power & Heat Generation (airport, hotels, hospitals, casinos, amusement parks, factories, mines, glass factories, paper mills and other industrial facilities)
- **Municipal – 5%**
 - Water Supply Pumping
 - Water Treatment
 - Landfills



Gaseous Fuels

Natural Gas

- Dry – 99% methane
- Wet – also has ethane, propane, butane, longer chain hydrocarbons or H₂O
- Sweet – no hydrogen sulfide, may have ethane
- Sour – contains sulfur compounds

Biogas

- Biogas – mixture of methane, carbon dioxide, trace amount of other gases
- Landfill – 50% methane, silicon, chlorofluorocarbons (CFC) corrosive acids
- Sewage – 60% methane, hydrogen sulfide



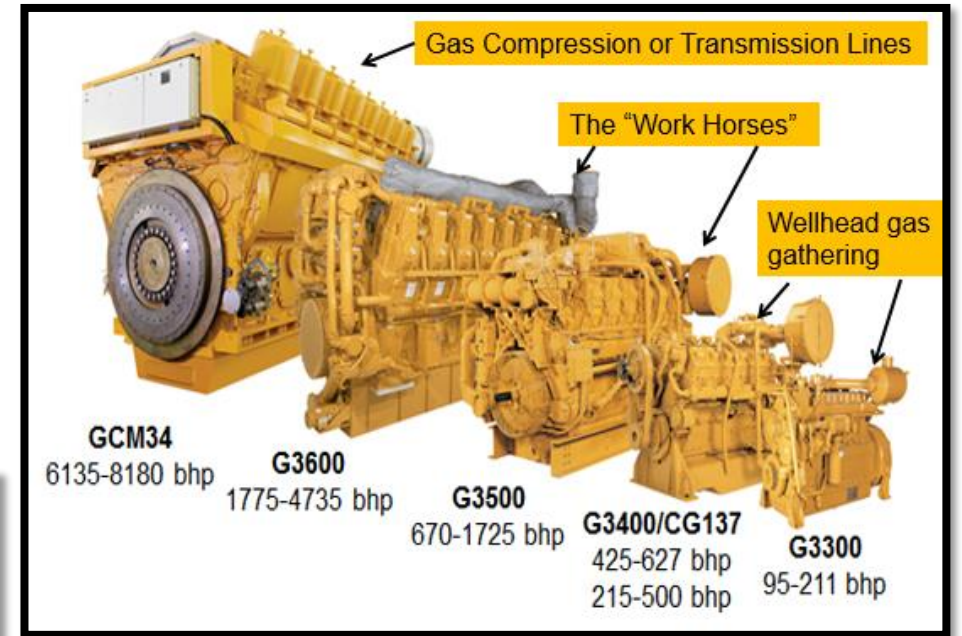
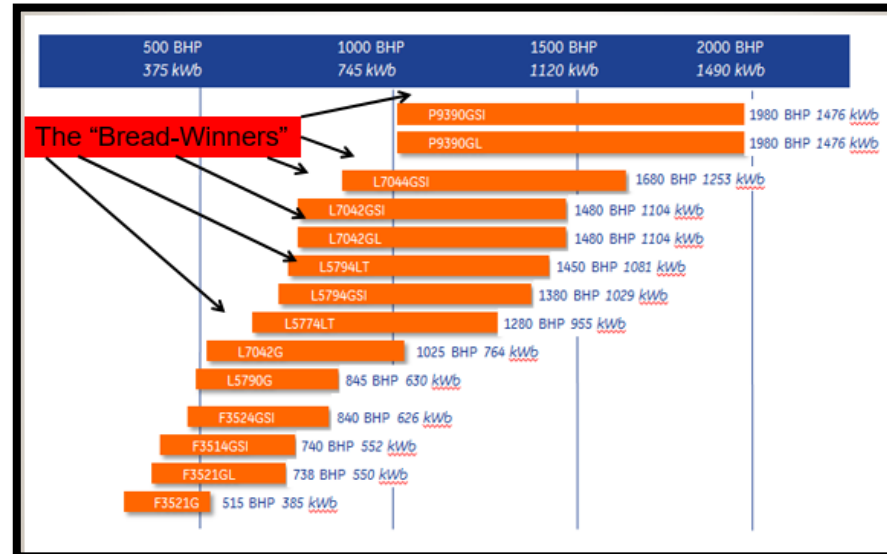
Major Original Equipment Manufacturers

- Caterpillar (about 50% of NA market)
- GE Power (Waukesha, Jenbacher, Cooper Bessemer, Superior, Ajax)
(Waukesha has about 25% of market)
- Cummins

Others

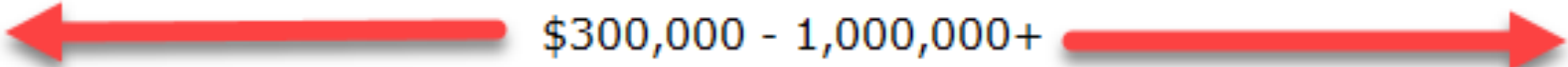
- Deutz Power Systems
- Niigata
- MDE
- Rolls Royce
- Wartsilla
- Clark

Waukesha Product Portfolio



Caterpillar Gas Compression Offerings

Typical Gas Engine Parameters

Manufacturer	Caterpillar	Waukesha	Jenbacher	Ingersoll-Rand
Engine Model	G3516	VHP L7044	Type 6	KVR
Cycle	4-T	4-T	4-T	2-T
Ignition	Spark	Spark	Spark	Spark
Breathing	Turbo-	Turbo-	Turbo-	Turbo-
Cylinders	16	12	16	16
Bore, mm (in)	170 (6.7)	238 (9.4)	190 (7.5)	432 (17)
Stroke, mm (in)	190 (7.5)	216 (8.5)	220 (8.7)	559 (22)
Displacement, L (cu in)	69 (4211)	115 (7037)	100 (6090)	1309 (79,897)
Weight, kg (K lbs)	7550 (17)	9525 (21)	23,600 (52)	140,000 (310)
Sump, L (gal)	360 (95)	720 (190)	530 (140)	7740 (2044)
Speed	1400	1200	1500	330
Power, kW (Hp)	1030 (1380)	1250 (1680)	2188 (2934)	4480 (6000)
Torque, N-m (ft-lb)	7020 (5180)	9970 (7350)	13,900 (10,270)	122K (90K)
	 \$300,000 - 1,000,000+			

Stationary Natural Gas Engine Oil Field Testing

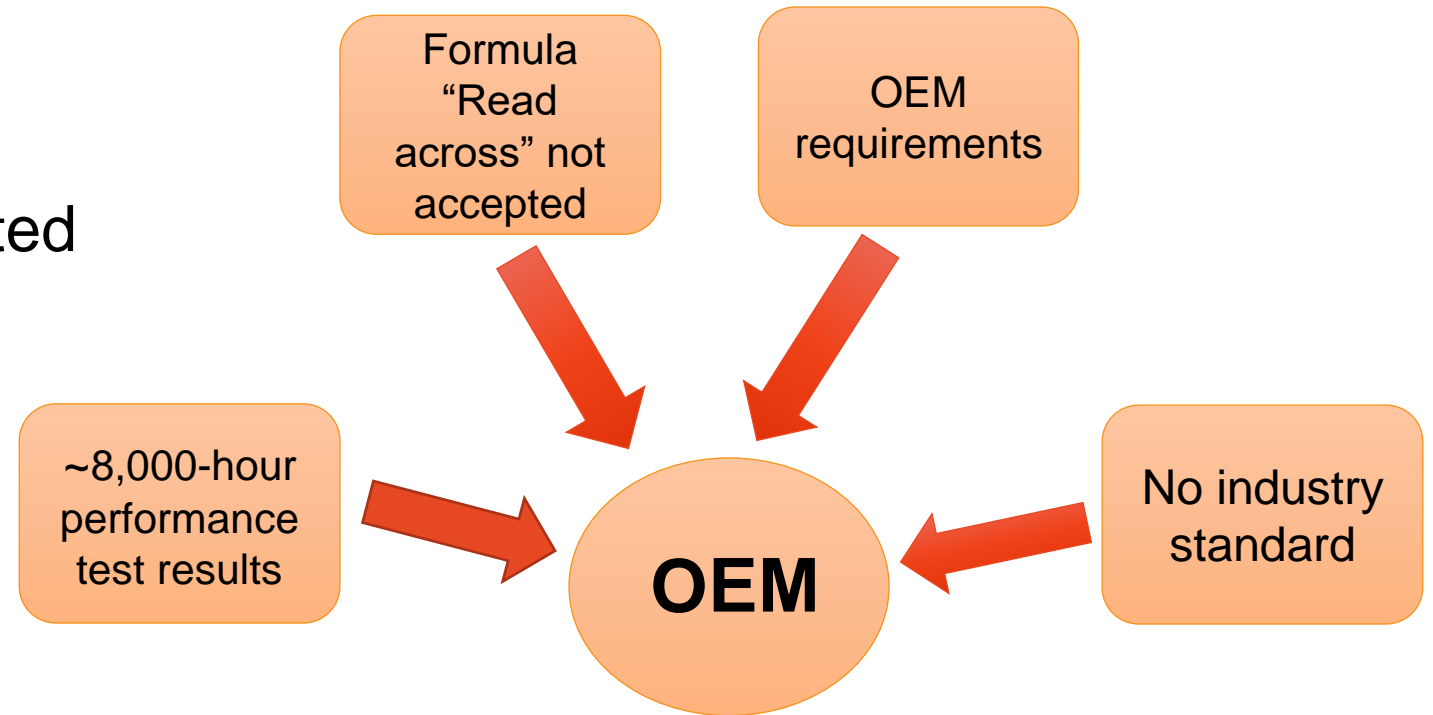
No industry oil standard

➤ Industry relies on real world performance

- Formula “Read across” is not accepted

➤ Performance is demonstrated by field test

- Under actual operating conditions



Stationary Gas vs. Diesel Engine Lubes

Natural Gas

No industry standard

Field testing for OEM approval

Low ash or ashless oils

SAE 40 preferred by OEMs

Diesel

Industry service classifications

Field testing not required

Mid ash oils

Multi-viscosity oils preferred by OEMs

Differences Between Natural Gas vs. Diesel Engines

Natural Gas

Variable burn characteristics

Carbureted

Combustible inlet

Fixed air/fuel ratio

Compression ratio 10:1

- Coolant temperature up to ~290°F
- Flame front, ~4,500°F

Exhaust ~300°F higher than diesel

24x7 operation

Low Ash oils

Diesel

Consistent burn characteristics

Injectors

Non-combustible inlet

Variable air/fuel ratio

Compression ratio 20:1

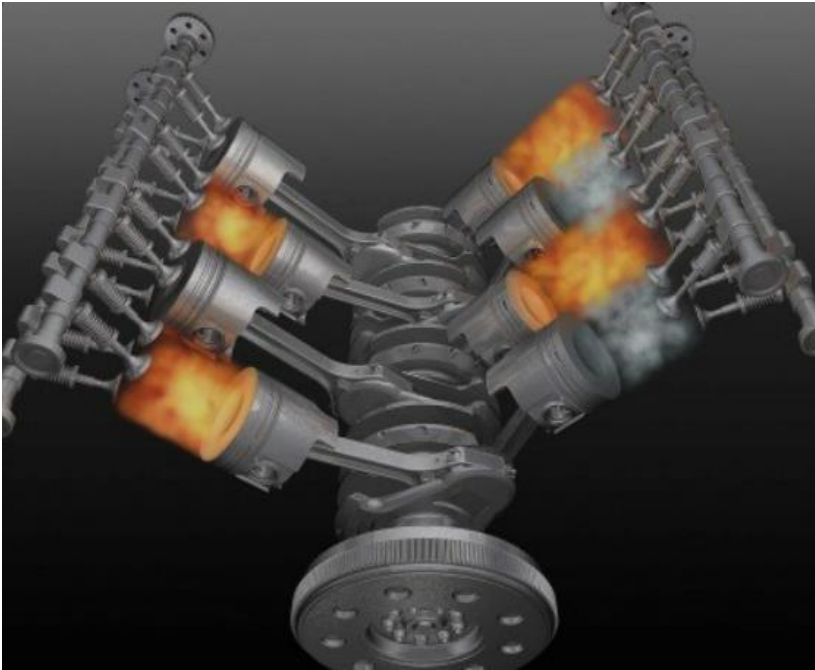
- Coolant temperature up to ~210°F
- Flame front, ~3,500°F

Intermittent operation

Mid Ash oils

Gas Engine Design

- Engines operating with gaseous fuels
- This is what makes them different



Reciprocating Internal Combustion Engines (RICE)

Sizes range from ~100 to ~10,000 HorsePower

- **Two or four stroke cycle**
 - 2-T: older, larger, medium-speed engines
 - 4-T: newer, smaller, high-speed engines
- **Spark ignited**
 - Or ignited with small injection of diesel fuel (dual-fuel)
- **May or may not have exhaust catalyst**
 - If so, phosphorous in lubricant is limited

Common Concerns - Gas Engines

➤ Safety

➤ Emissions

- Necessary to stay in business
- Target of increasing legislative pressure

➤ Reliability

- Generate revenue
- Minimize down-time
- Lives could depend on it

➤ Durability

- Minimize maintenance cost
- Extend time between overhaul
- Extend drain interval
- Lengthen profitable life of asset



Stationary Natural Gas Engines

High Load

- Severe oil stress

Remote Operation

- Reliability essential

Variety of Engine Types

- Flexible products

Fuel Variation

- Gas composition
- Btu content



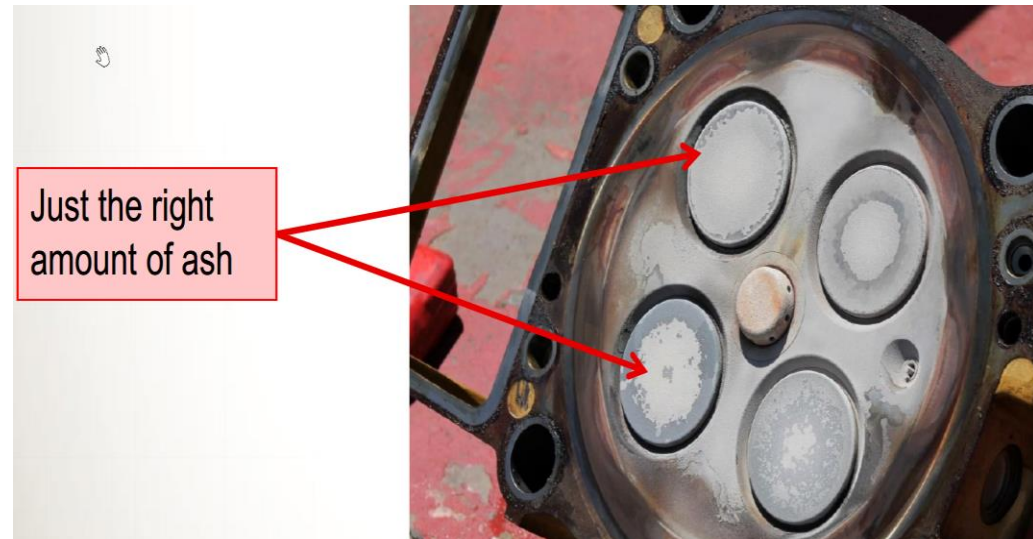
Sulfated Ash

Segmentation by Ash (Sulphated ASH = SASH)

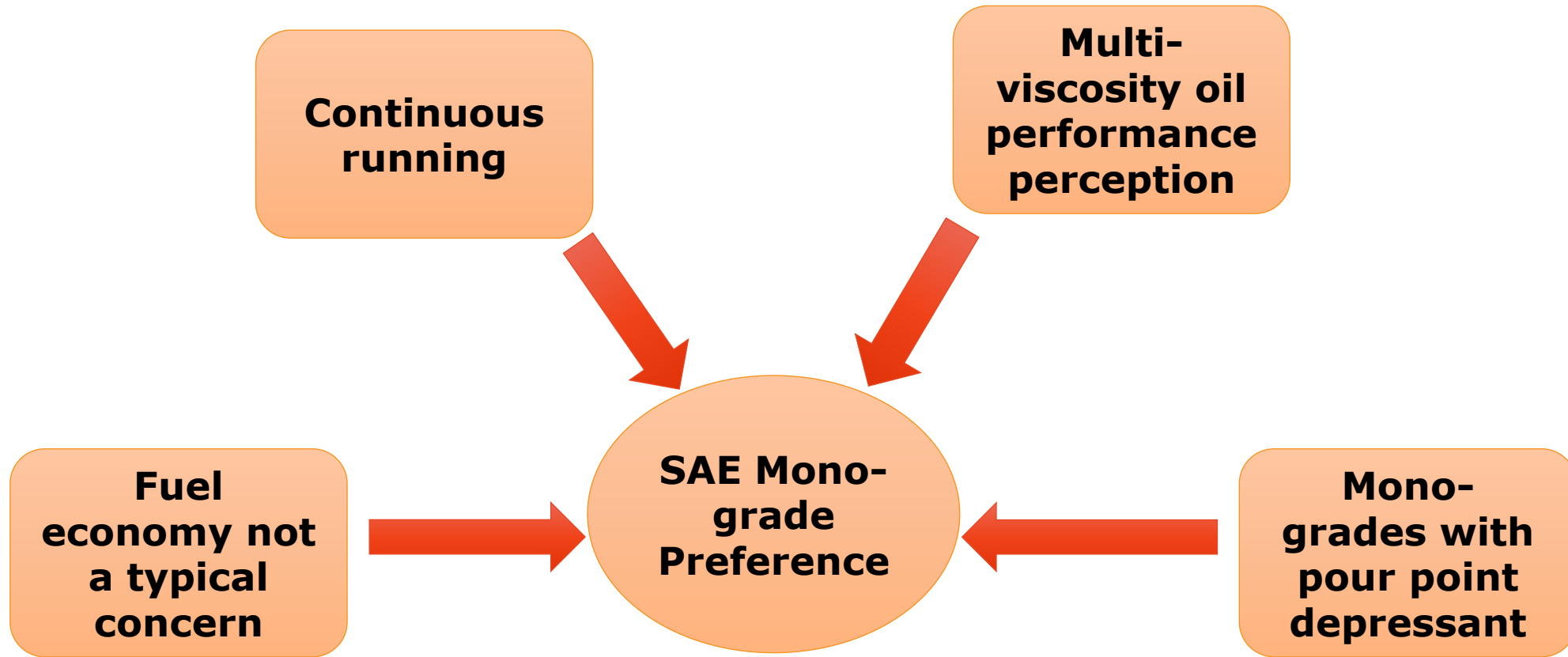
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|------------------|-----------------------|------------------------------|
| ▪ <u>Ashless</u> | < 0.1 SASH | Older 2-stroke |
| ▪ <u>Low ash</u> | 0.1 – 0.5 SASH(→ 0.6) | Most common |
| ▪ Medium ash | 0.5 – 1.0 SASH | High sulfur gas / some OEM's |
| ▪ High ash | > 1.0 SASH | Very high sulfur gas |

Ash residue left after oil is burned

- Detergent dispersant additives contribute to SASH
- Dry film lubrication for valves
- More not necessarily better



Stationary Natural Gas Engine and SAE Grades



Engine Oil Viscosity Grades

Monograde

High temperature / high shear viscosity requirements at 150°C

Defined viscosity range at 100°C

Multi-Grade

“Flatter” viscosity temperature relationship

“W” grade requirements: low temperature cranking, pumping

Defined viscosity range at 100°C

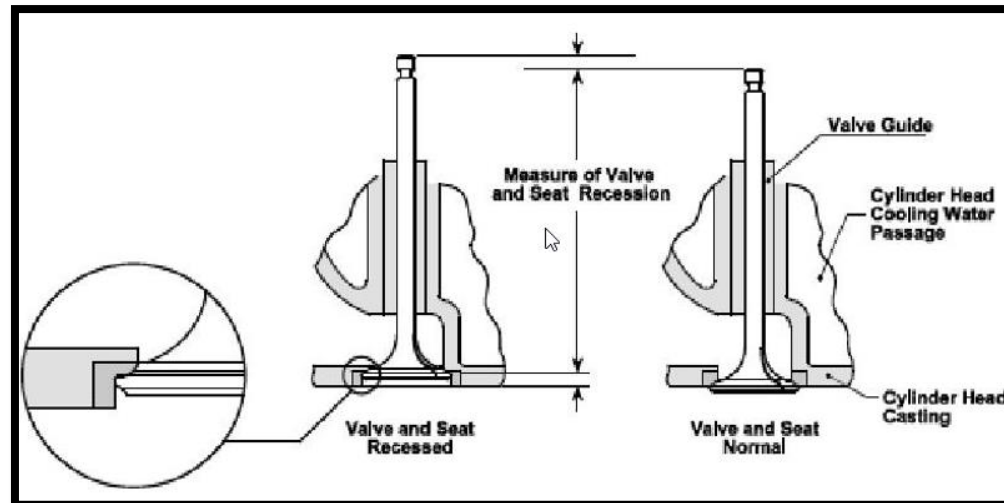
Natural Gas Engine Oil Consideration

- Oil formulation must control nitration effects in 4-stroke engine
 - Oil viscosity control
 - Deposit formation prevention
- Ash content
 - Ashless for two stroke engine port deposit control
 - Ash for four stroke engines valve protection



Port Plugging

Valve Recession





Natural Gas Engine Oil Consideration

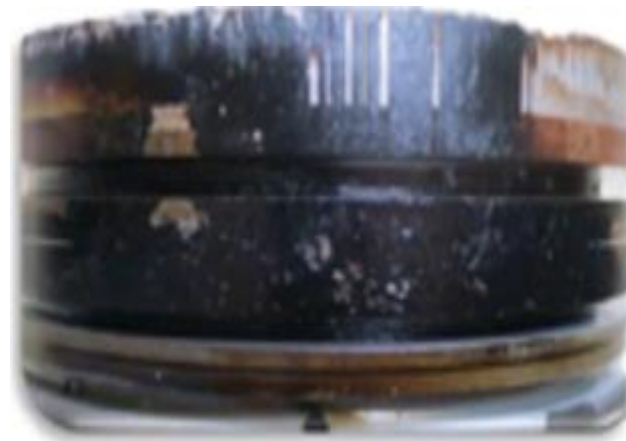
- Emission catalyst systems limit the amount of certain oil additives
 - Zinc and phosphorous limits
- Oil must have the capacity to absorb acids formed during combustion
 - TBN reserve
- Correct viscosity grade
 - Majority used is SAE 40
 - SAE 30 and multi-grades also available

4-Stroke Key Lubricant Performance Properties

- Oxidation Control
- Nitration Control
- Minimize Valve Recession
- Prevent Rust and Corrosion
- Keep Engine Parts Clean



Piston



Acid Attack

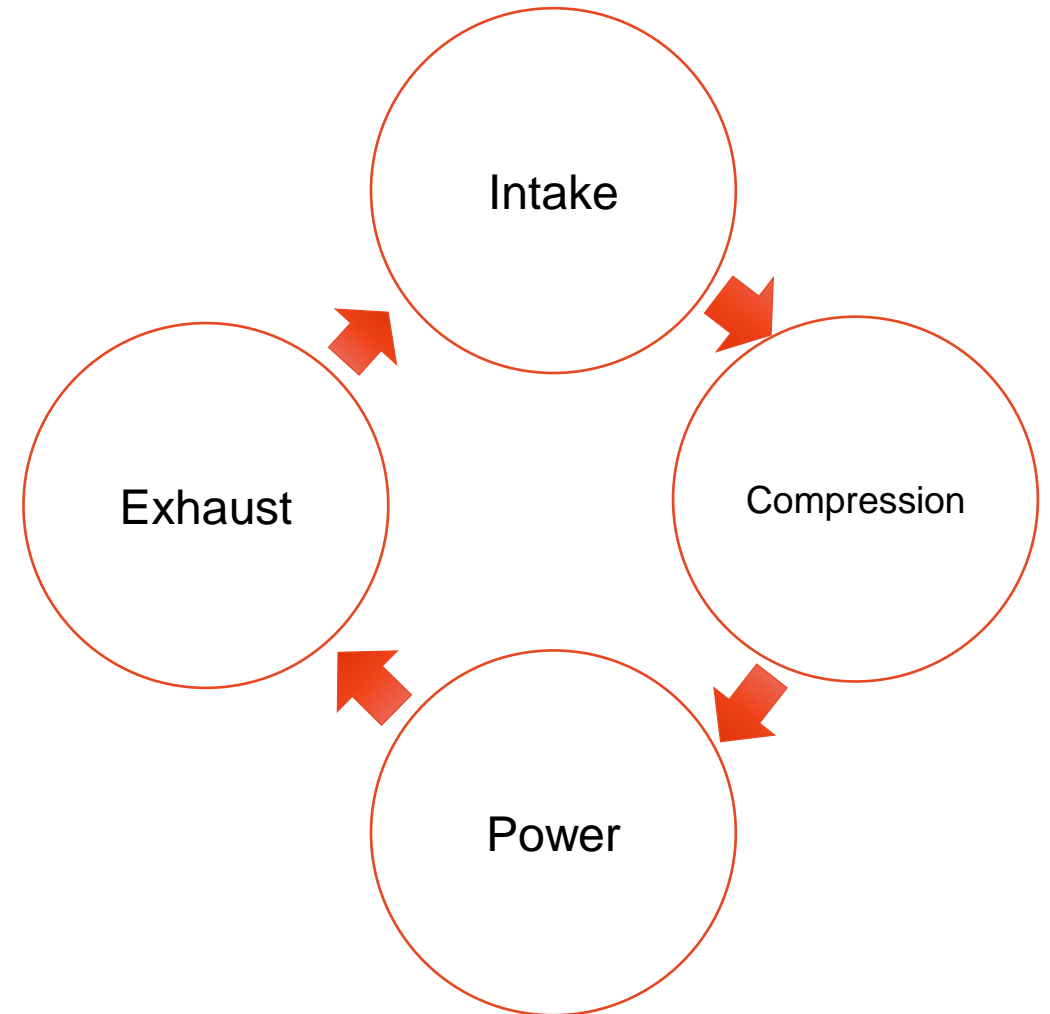
4-Stroke Stationary Natural Gas Engine

➤ Four Stroke

- Up to 8,180 hp
- Medium to high speed (750 – 1,500)
- Naturally aspirated or turbocharged
- Intake and exhaust valves



Valve



Natural Gas Engine Problems

➤ **Unique combustion chemistry**

- Gaseous fuel – fully mixed flame
- High combustion temperature
(exhaust $\sim 590^{\circ}\text{C}$ vs $\sim 470^{\circ}\text{C}$ diesel)

➤ **High oil oxidation and nitration**

- Anti-oxidant selection is critical

➤ **Corrosion**

- Oxidation acids, sulfur and other contaminants in sour gases

➤ **Deposits**

- Varnish (high temperature deposits)
- Siloxane (silicon compounds) from landfill gas

➤ **Water Formation**

- Higher than liquid hydrogen fuel

➤ **No valve lubrication from liquid hydrocarbon fuel**

- Rely on ash from burned engines oil to lubricate valves
- Lubricating oil SASH is an important parameter





Air Fuel Ratio

➤ Rich burn (rich exhaust)

- AFR of 15:1
- More fuel for approximately the same amount of oxygen

➤ Result

- Higher fuel consumption
- Additional power
- Excess fuel remaining in the exhaust
- Lower combustion temperature
- Less NO_x

➤ Lean burn (lean exhaust)

- AFR 17.00 & 18.00:1
- Less fuel for approximately the same amount of oxygen

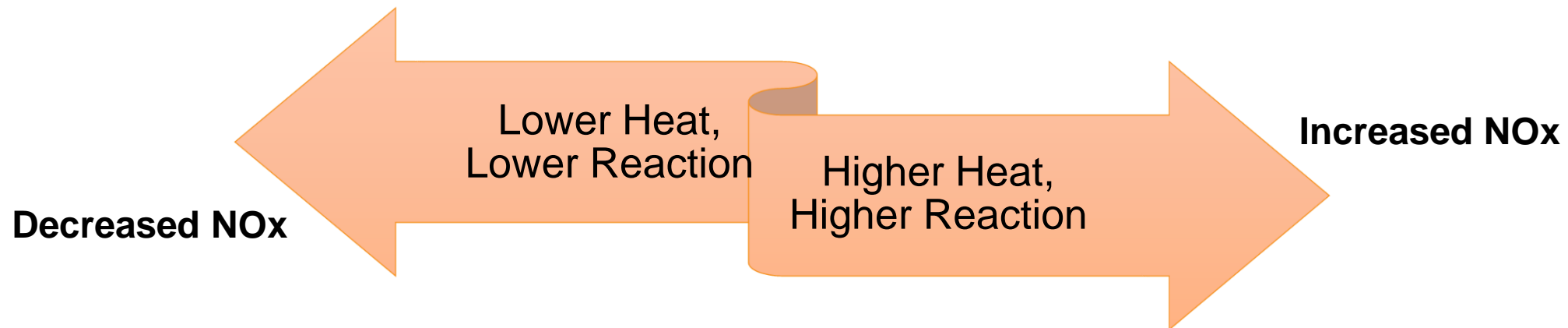
➤ Result

- Excess oxygen in combustion chamber
- Lower fuel consumption
- Loss of power
- Increase in NO

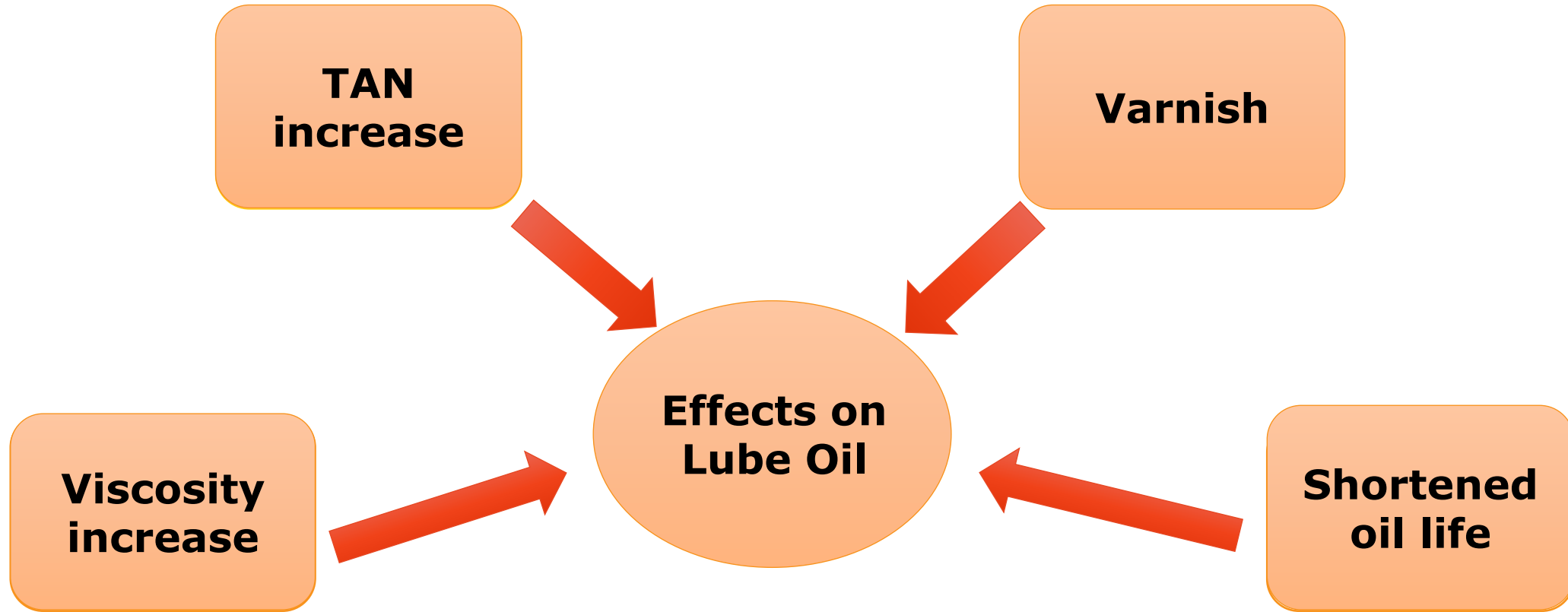
Nitration and Combustion Temperature

Nitration

- NOx formation is dependent on time and temperature
- Maximum NOx occurs when sufficient heat in the combustion chamber reacts with oxygen
- Nitration peaks when AFR is between 18.00 and 19.00:1, just right of stoichiometric
- NOx combines with lube oil
 - Blow by gases
 - Forms nitration compounds
 - Leads to oil degradation



Nitration in Natural Gas Engines

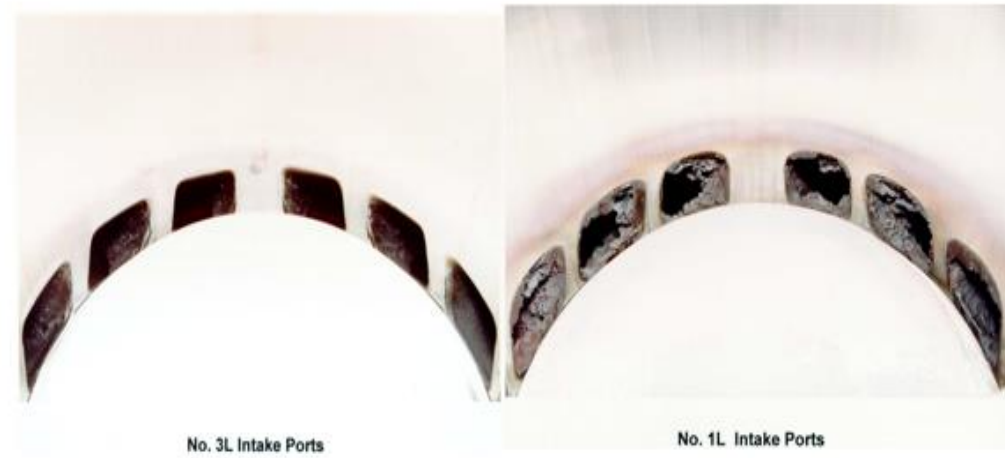


2-Stroke Key Lubricant Performance Properties

- **Minimize Port and Chamber Deposits**
- **Keep Engine Parts Clean**
- **Reduce Wear**
- **Prevent Rust and Corrosion**



Port Plugging

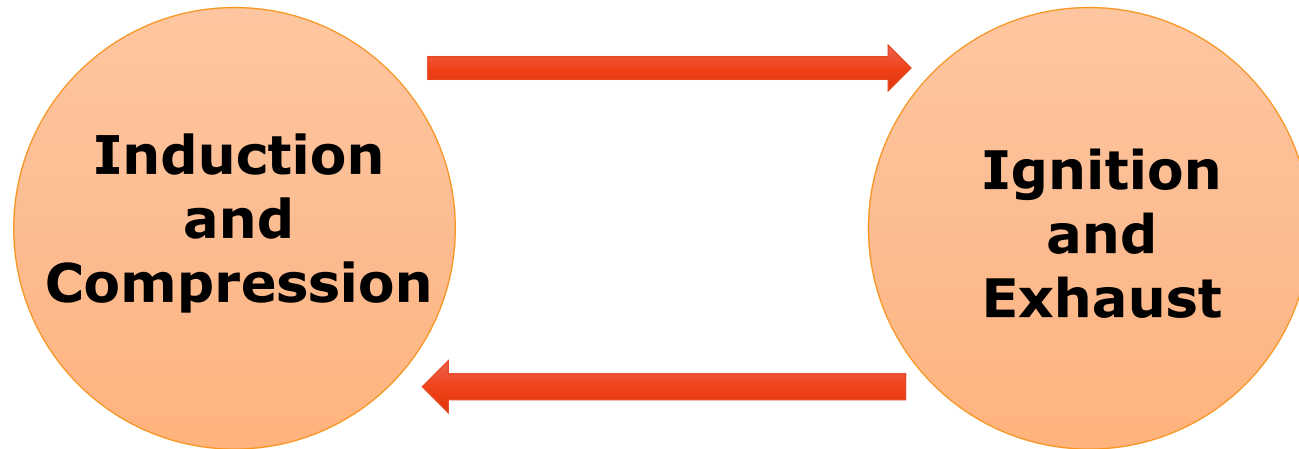


Good

Bad

2-Stroke Stationary Natural Gas Engine

- Typical Two Stroke Engines
 - Up to 15,000 hp
 - Slow speed (<500 rpm)
 - Naturally aspirated and turbocharged
 - Requires ashless engine oils
 - Intake and exhaust ports
- Small units used in gas gathering



2-Stroke Engine

Landfill Gas to Energy

➤ Operation

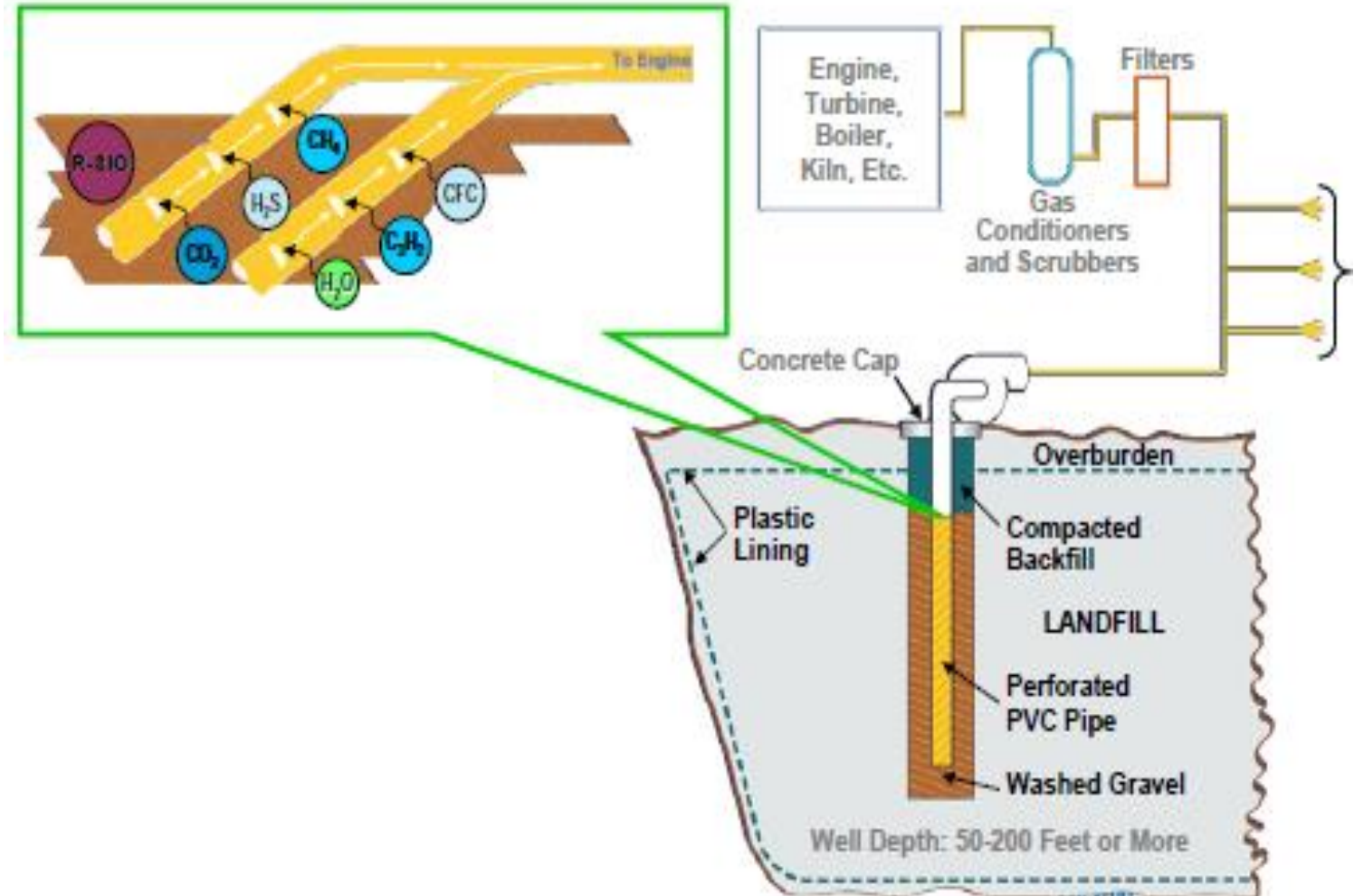
- Almost always four stroke
- Usually run unattended
- Usually well maintained
- Usually run at 100% load
- Normally more than one engine in a room
- Often Caterpillar or Jenbacher



Landfill Gas to Energy

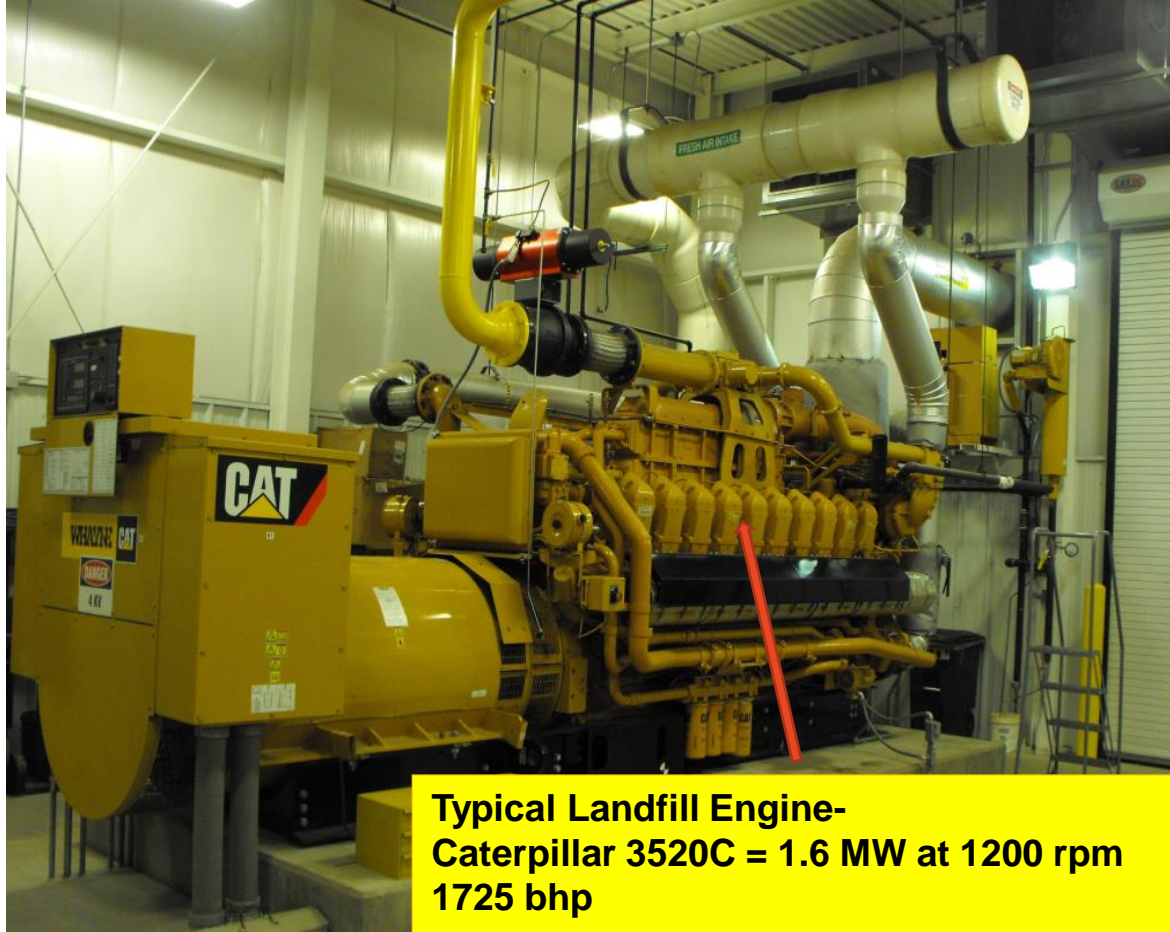
Common Problems

- Low gas quality
 - Low energy content
 - Usually contains H₂O
 - May contain CFC's
 - H₂S, Siloxane's
- Frequent maintenance
- Frequent oil changes
- Valve deposit build-up
- Liner laccqueing
- Corrosion related failures



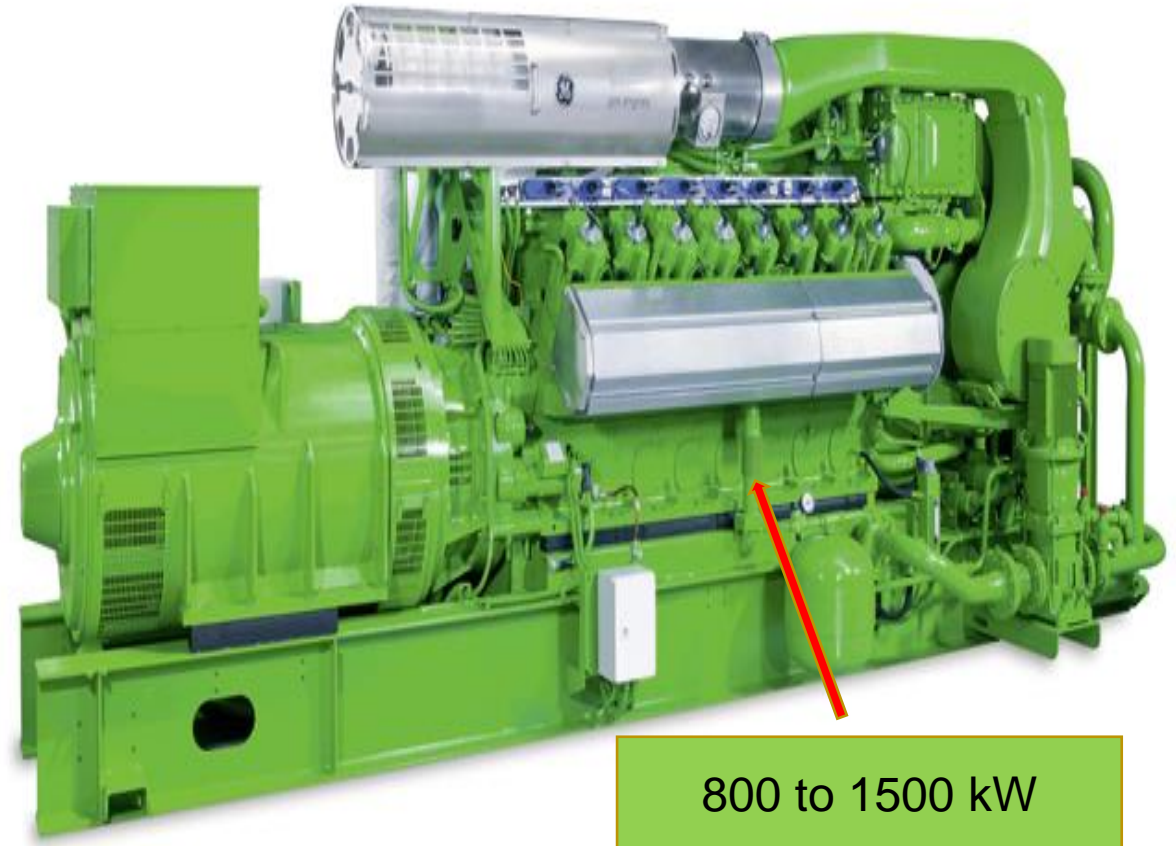
Typical Landfill Engine

Caterpillar 3520C



Typical Landfill Engine-
Caterpillar 3520C = 1.6 MW at 1200 rpm
1725 bhp

Jenbacher – Series 4



800 to 1500 kW

Application Comparison

Application	Type	Typical kW at rpm	Typical Crankcase Volume	Typical Oil Consumption	Oil Type
Transmission	2-Stroke	7547 at 330	1347 gal	10-14 gal/day	Ashless
Gas Gathering	4-Stroke	850 at 1200	110 gal	1.7-3.7 gal/day	Low Ash
Electrical Gen	4-Stroke	1600 at 1500	106 gal	0.8-1.8gal/day	Low Ash
Mobile Gas Eng	4-Stroke	205 at 2100	7.5 gal	Very Low	Low Ash +



CITGO Natural Gas Engine Oil Product Line

CITGO Pacemaker GEO 4-Stroke Products

Low Ash Gas Engine Oil

Pacemaker GEO 1900XL Series

- Low ash product designed for use in 4-stroke engines that are naturally aspirated and turbocharged.
- Unsurpassed performance in severe nitration & oxidation application
- Offers enhanced extended drain capability
- SAE 30, 40 and 15W-40
- Formulated with PPD to improve low temperature properties
- GEO 1940XL is an approved oil for use in Caterpillar G16CM34.
- Recommended for high and medium speed 4-stroke engines manufactured by Caterpillar, Waukesha, Superior, Jenbacher, Warsilla, and Dresser-Rand (Categories I, II and III). Low speed engine for Cooper Bessemer and Worthington

CITGO Pacemaker GEO 4-Stroke Products

Low Ash Gas Engine Oil

Pacemaker GEO 1600 Series

- Is a premium low ash product designed for use in 4-stroke engines
- Offers extended drain interval capability
- Additional antioxidant provides improved oxidation and nitration stability
- SAE 30, 40 and 15W-40
- Formulated with PPD to improve low temperature properties
- Suitable for a wide range of engines operating on any variation of natural gas.
- Recommended for high and medium speed 4-stroke engines manufactured by Caterpillar, Waukesha, Superior, Cooper Bessemer, Dresser-Rand (Categories I, II and III) and low speed engines manufactured by Worthington C 4-stroke

CITGO Pacemaker GEO 4-Stroke Products

Low Ash Gas Engine Oil

Pacemaker GEO 1400 Series

- Is a low ash product and offers extended drain interval capability.
- Provides improved oxidation and nitration stability
- SAE 30, 40 and 15W-40
- Low pour point to improve low temperature properties
- Recommended primarily for use in lubrication of spark ignited 4-stroke stationary natural gas engines and compressor cylinders.
- Suitable for use in catalytic converter systems.
- Recommended for high and medium speed naturally aspirated and turbo charged 4-stroke stationary natural gas engines manufactured by Caterpillar, and Waukesha.

CITGO Pacemaker GEO 4-Stroke Products

Mid Ash Gas Engine Oil

Pacemaker GEO 700 Series

- This is a premium medium ash (0.9% SASH) product designed for use in 4-stroke engines.
- Higher TBN will offer greater protection against acid increase and corrosive wear from sour gas.
- Contains higher zinc level for anti-wear and is recommended for use in engines converted to natural gas.
- **NOT RECOMMENDED FOR ENGINES EQUIPED WITH CATALYTIC CONVERTERS.**
- Available in SAE 40 and 15W-40.
- Recommended for medium and high speed, high output 4-stroke engines in field gathering service.
- Recommended for engines in cogeneration service, digester gas fueled, dual fueled and diesel-fueled service.

CITGO Pacemaker GEO 4-Stroke Products

Specialty Gas Engine Oil

Pacemaker LFG LA 40

- This is a premium low ash product designed for high output 4-stroke natural gas engines operating on landfill and digester gas.
- The product is specially formulated to neutralize combustion acids from landfill and digester gas.
- Offers extended drain interval and is extensively tested in field trial and approved by GE Jenbacher for use in Type 2, 3, 4 and 6 engines (fuel class B and C)

Pacemaker GEO 15SL

- Low ash stationary gas engine oil formulated with synthetic base stock and advanced additive system.
- This is a high zinc containing product and is recommended for use in stationary engines converted to natural gas such as irrigation pump service and LP (liquid propane) applications.
- Drastically extends oil service life compared with conventional engines oil.

CITGO Pacemaker GEO 2-Stroke Product

Ashless Gas Engine Oil

Pacemaker GEO 1000 Series

- Is a premium ashless product designed for use in 2-stroke engines that are naturally aspirated and turbo charged.
- Offers extended oil life capable
- GEO 1000 series minimizes port plugging, piston deposit and controls wear.
GEO 1035 and 1040 are formulated to provide enhanced low temperature properties.
- Available in SAE 30/40, SAE 40 and SAE 15W-40
- Recommended for use in 2-stroke engines such as Ajax, Clark, Dresser-Rand, Cooper-Bessemer, Worthington, and Fairbanks-Morse, as well as gas engine manufacturers requiring ashless engine oils.

Mystik Terra GEO 4-Stroke Products

Low Ash Gas Engine Oil

TerraSyn Irrigation Engine Oil

- Full synthetic for use Irrigation Pump Services
- For use in Gasoline Engines converted to natural gas fuels
- Enhanced extended drain capability
- Available in SAE 15W-40
- Low pour point to provide low temperature properties

Terra 500 GEO SAE 15W-50

- Recommended where low ash oil are permitted, in low, medium and high speed 4-stroke engines. Catalyst compatible
- Oxidation and nitration control condition
- Extended oil life capable
- Available in SAE 15W-50

Terra 340 GEO

- Recommended where low ash oil are permitted, in low, medium and high speed 4-stroke engines. Catalyst compatible
- Oxidation and nitration control condition
- Extended oil life capable
- Available in SAE 30, 40 and 15W-40

Mystik Terra GEO 2-Stroke Product

Ashless Gas Engine Oil

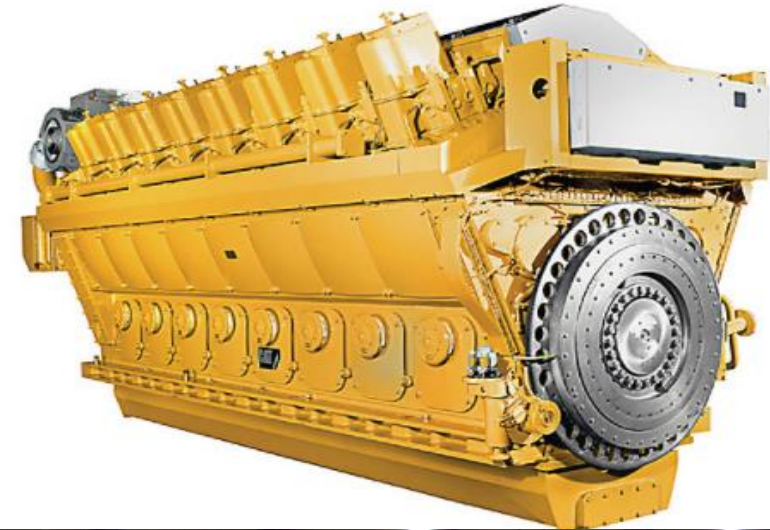
Terra Free Ashless Gas Engine Oil

- Recommended where ashless oils are permitted in low to medium speed 2 and 4- stroke engines requiring ashless gas engine oil
- Offers extended oil life capable
- Excellent choice for catalytic converter equipped engines
- Recommended for all-natural gas and propane powered engines which specify an ashless engine oil
- Available in SAE 30, 40 and 15W-40
- Formulated with PPD to provide low temperature properties

CITGO Pacemaker GEO 1940XL on CAT G16CM34 Approval

Proof of Oil Performance

- Engine driving Ariel KBB for gas compression
- Test completed in 2019
- Total hours on test 8,588 hours
- CITGO Pacemaker 1940XL is the first commercial lubricant in the US to obtain approval
- CAT engineers endorsed the use of CITGO Pacemaker 1940XL for use in its CAT G16CM34



CAT G16CM34 Engine Inspection Photos

Piston



Piston Rings



Valve Seats



A3 Intake Valves

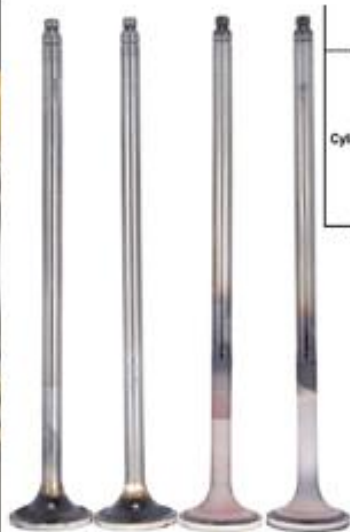


A3 Exhaust Valves

Combustion Surface



Valves



Inboard

Outboard

Inboard

Outboard

CITGO Pacemaker GEO 1640

Performance comparison

CITGO
Pacemaker
GEO 1640
vs.
Commercial
Oil 2M

- Back-to-back test in the same Caterpillar G3516 TALE
 - 8,584 hours: CITGO Pacemaker GEO 1640
 - 8,574 hours: Commercial Oil 2M
 - Compression service, pipeline quality gas
 - 85 – 90% engine load during test
 - Used oil analysis over life of test
 - New power assemblies at start of each test; evaluated at end of test inspections on each oil
 - Pistons, cylinder heads, rod bearing
 - Various covers and rocker arm assemblies

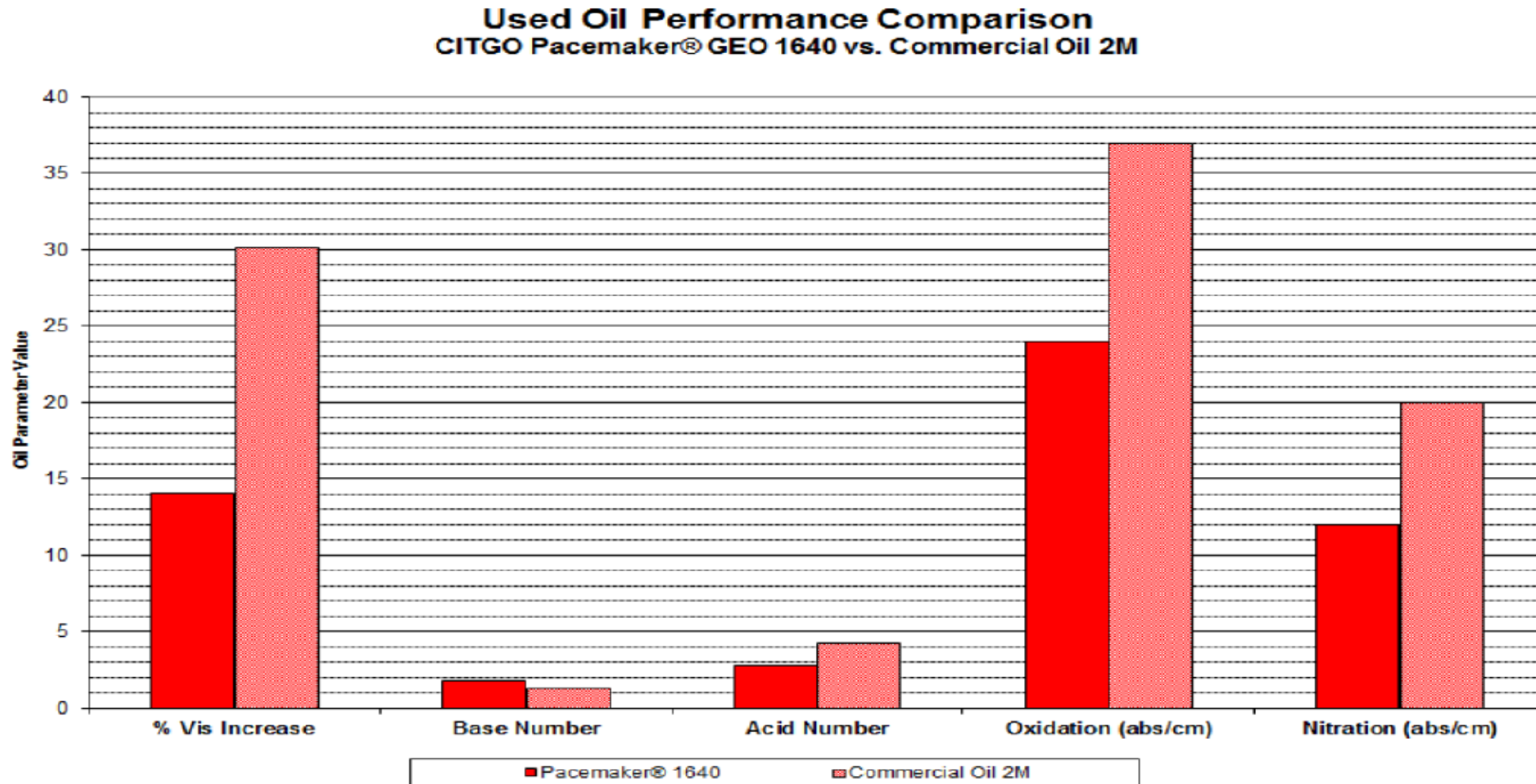
CITGO Pacemaker GEO 1640

Comparison Summary

	CITGO Pacemaker® GEO 1640	Competitor 2M
	Cat G3516 TALE	Cat G3516 TALE
Hours	8584	8574
Average Oil Drain (hours)	2018	1712
Sludge, Merit	9.92	9.55
Ring Sticking, Merit	10	10
Piston Deposits, Demerits	69.6	75.5
Piston Top, Demerits	16.75	23.1
Fireface, Demerits	17.6	27.1

CITGO Pacemaker GEO 1640

Performance comparison



CITGO Pacemaker GEO 1640

Comparison Summary, Caterpillar G3516 TALE

CITGO
Pacemaker
GEO 1640
provides
improved
performance
in oil life and
engine
cleanliness

- Better viscosity control, oxidation and nitration control base retention and acid control
- Achieved ~300 hours additional oil drain life (18%) vs. Competitor Oil 2M
- Overall reduced deposits compared to Commercial Oil 2M



GEO LubeAlert Used Oil Monitoring Program

- Only available to CITGO customers
- Reports include
 - Identification of contaminants
 - Wear metals trend analysis
 - Monitoring viscosity
 - Monitoring oxidation and nitration
 - TAN
 - % H₂O
 - E-mail notification / easy LubeAlert website use



Questions

- Please post your questions using the Q&A function.



How to Contact Us

- Lubes Answer Line
- **800-248-4684**
 - 8:00 AM - 12:00 PM, 1:00 PM – 5:00 PM CT (Mon – Thurs)
 - 8:00 AM - 12:00 PM, 1:00 PM – 4:30 PM CT (Fri)
- lubeshelp@citgo.com
 - Available 24/7



Future Webinars

Future Webinar Date

December 2, 2022

December 16, 2022

Future Webinar Title

Wireline Lubricant

Industrial Gear and Gear Lubrication