



CITGO Pacemaker Gas Engine Oil

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- **BS, Chemistry**
- **15 Years Experience in Lubricants**
- **STLE Certified**
 - **Oil Monitoring Analyst I**





Gas Engine Oil Agenda

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

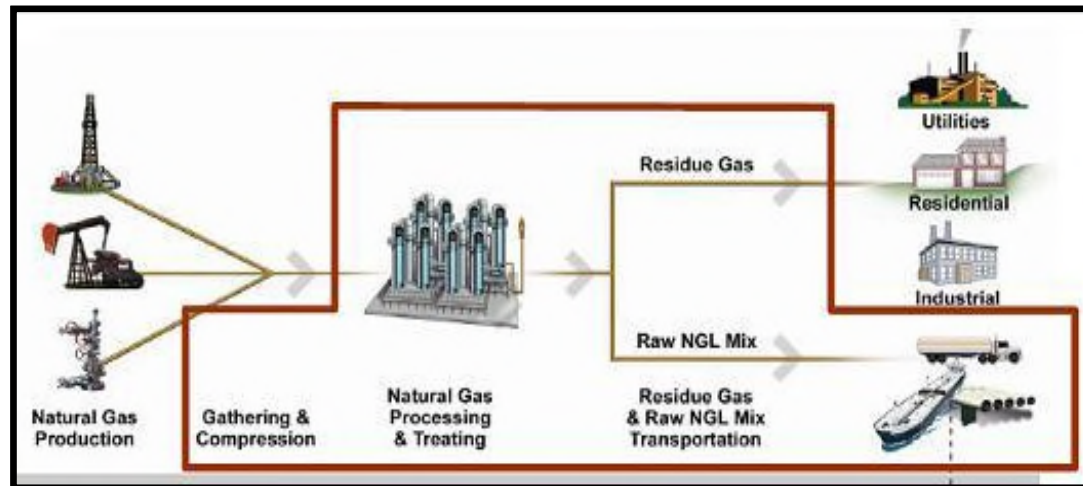
NGEO Application – Wellhead to Consumers

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, Some Co-Generation 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



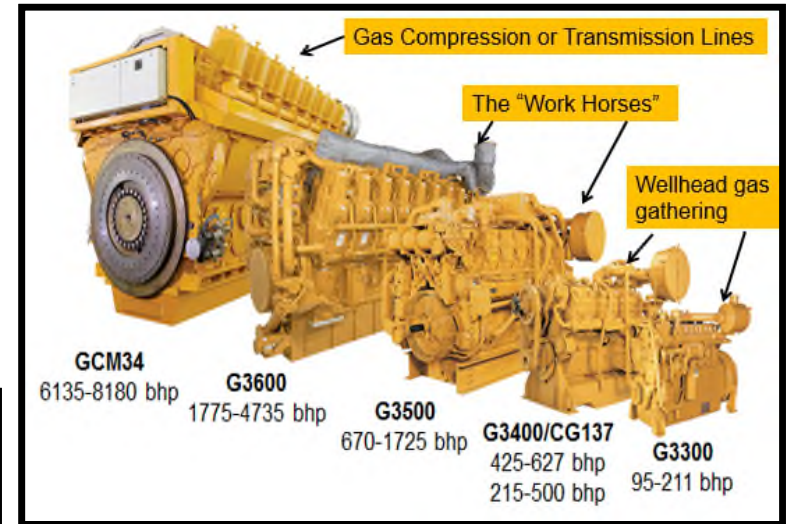
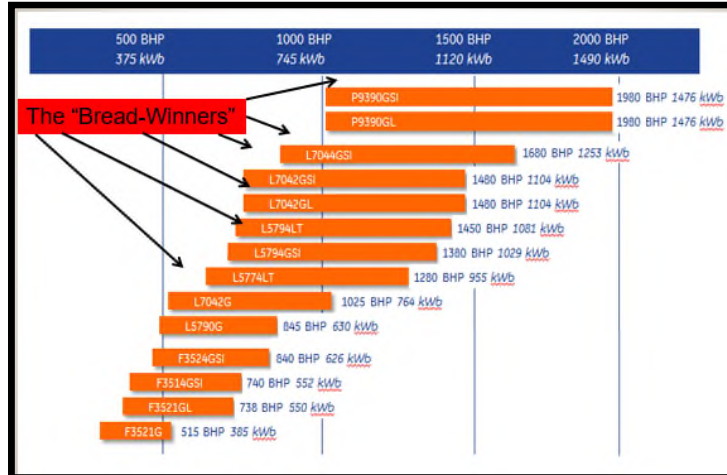
Major Original Equipment Manufacturers

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

Others

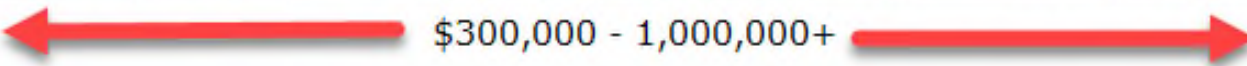
- Deutz Power Systems
- Niigata
- MDE
- Rolls Royce
- Wartsilla
- Clark

Waukesha Product Portfolio



Caterpillar Gas Compression Offerings

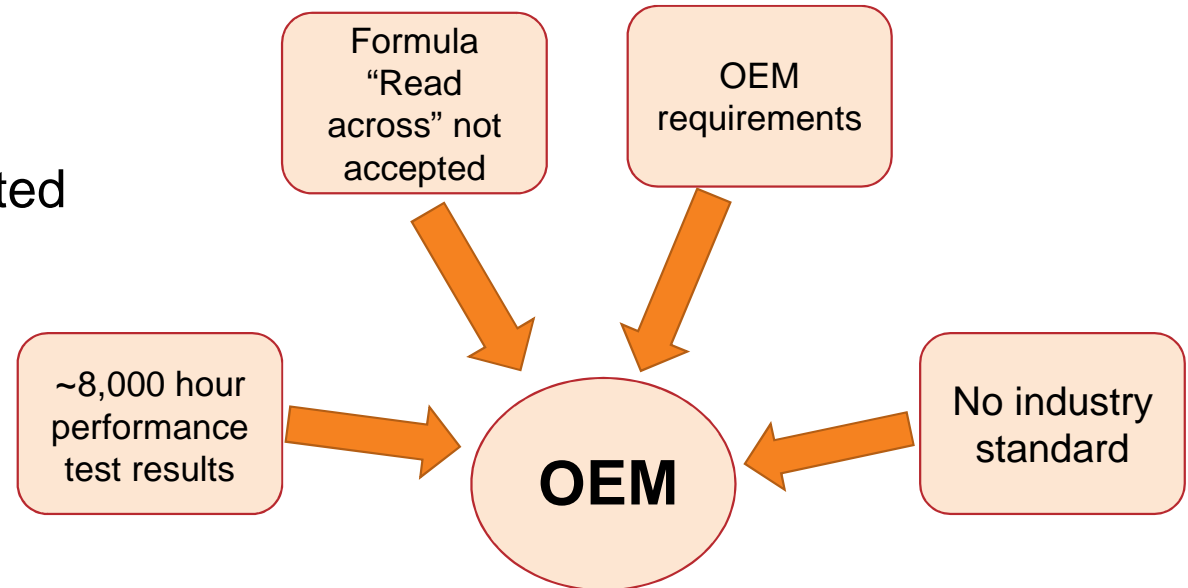
Typical Gas Engine Parameters

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)
				

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



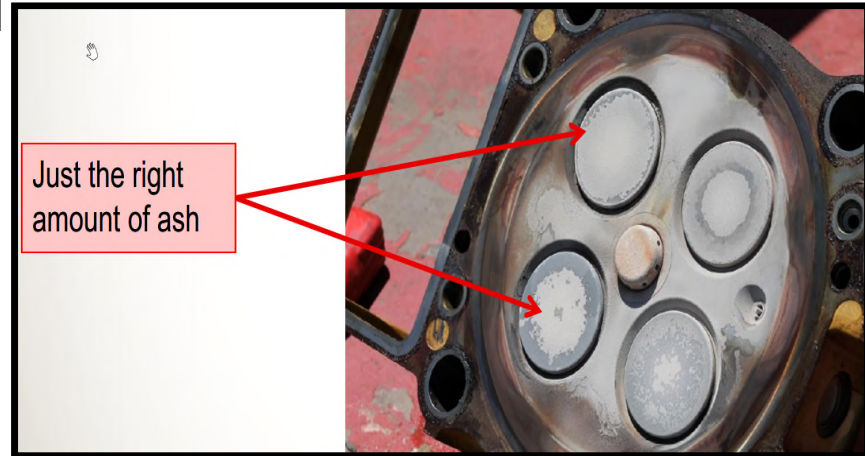
Sulfated Ash

Segmentation by Ash (Sulphated ASH = SASH)

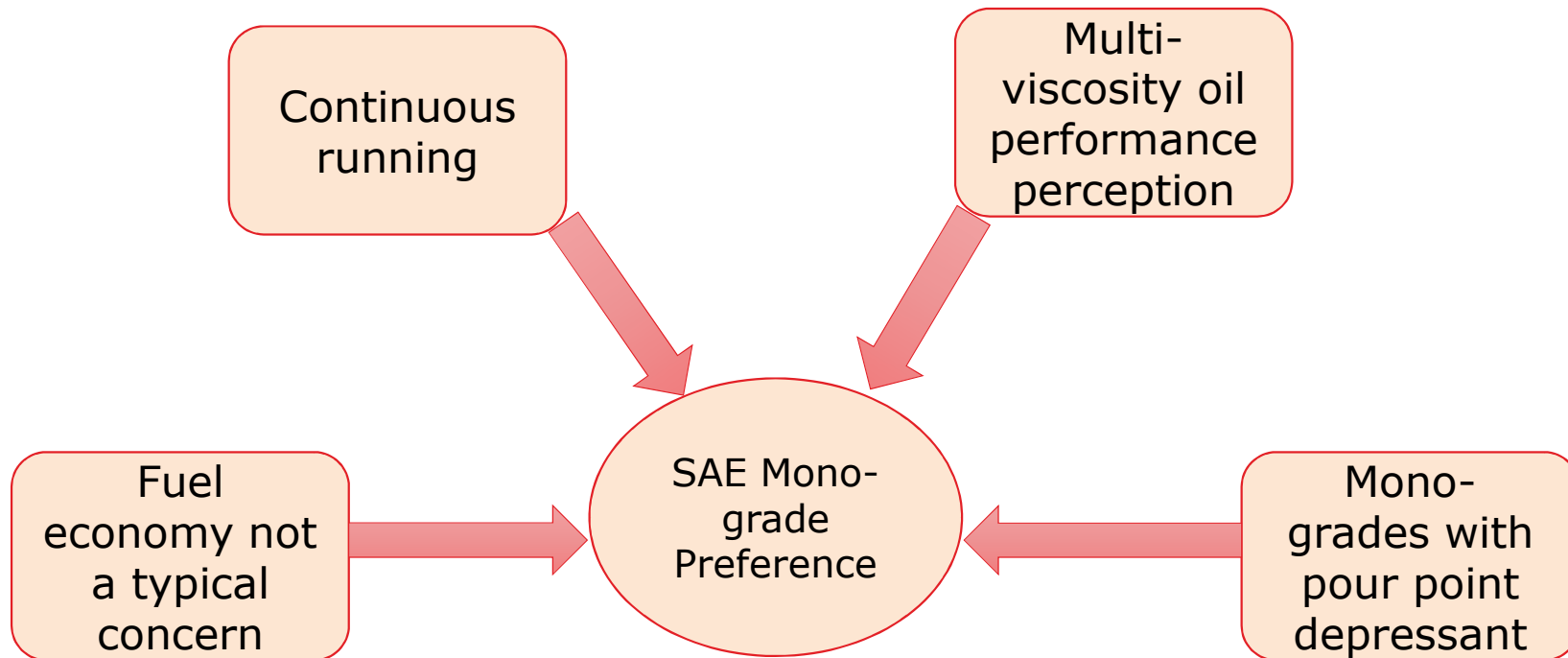
▪ <u>Ashless</u>	< 0.1 SASH	Older 2-stroke
▪ <u>Low ash</u>	0.1 – 0.5 SASH(→ 0.6)	Most common
▪ Medium ash	0.5 – 1.0 SASH	High sulfur gas / some OEM's
▪ High ash	> 1.0 SASH	Very high sulfur gas

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

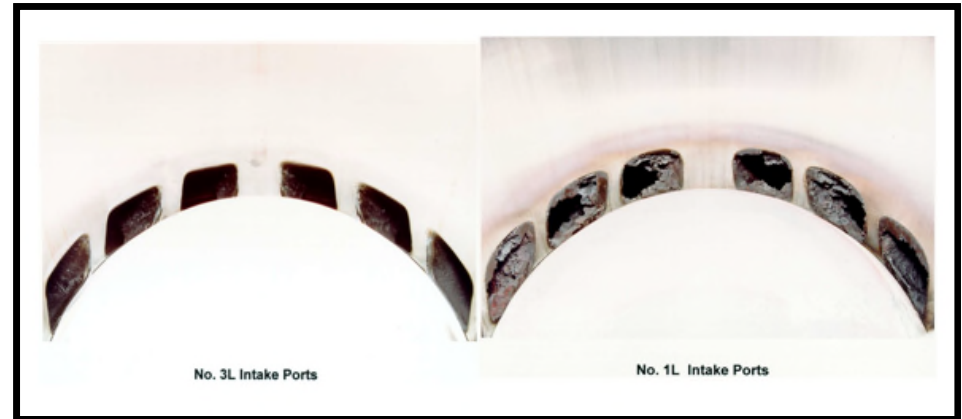
“Flatter” viscosity temperature relationship

“W” grade requirements: low temperature cranking, pumping

Defined viscosity range at 100°C

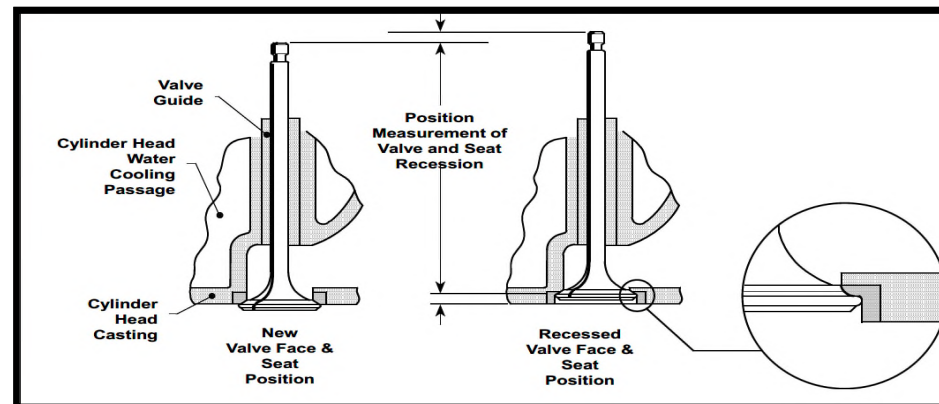
Natural Gas Engine Oil Consideration

- Oil formulation must control nitration effects primarily 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 Position Measurement





Natural Gas Engine Oil Consideration

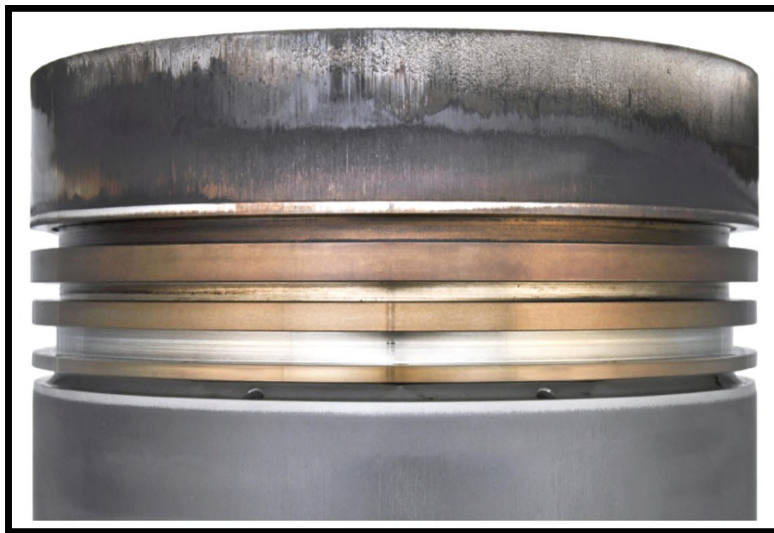
- Emission catalyst systems limit the amount of certain oil additives
 - Zinc and phosphorous limits

 - Oil must have the capacity to absorb acids formed during combustion
 - TBN reserve

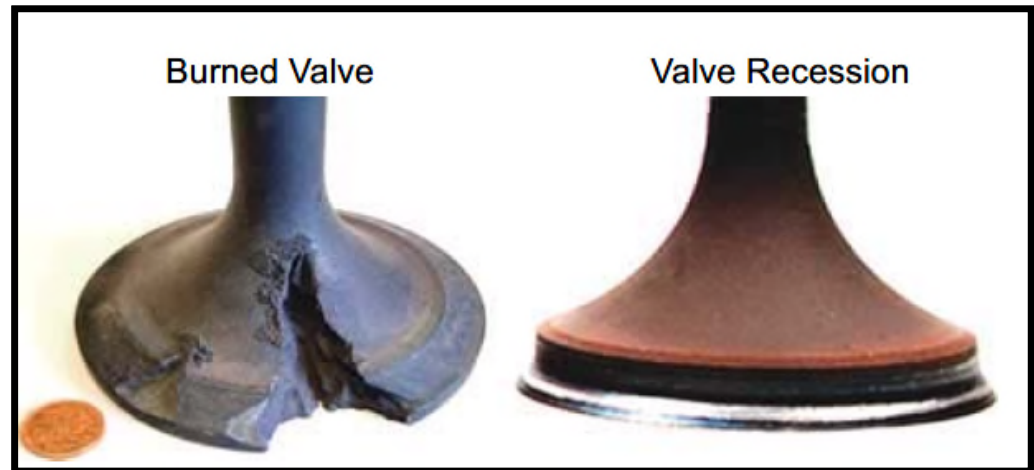
 - Correct viscosity grade
 - Majority used is SAE 40
 - SAE 30 and multi-grades also available
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4-Stroke Key Lubricant Performance Properties

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



Piston



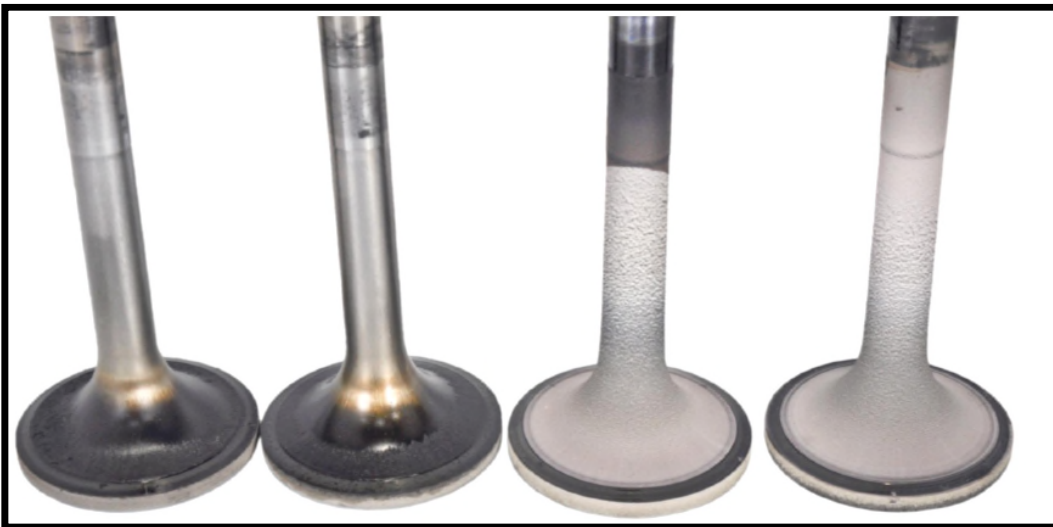
Acid Attack



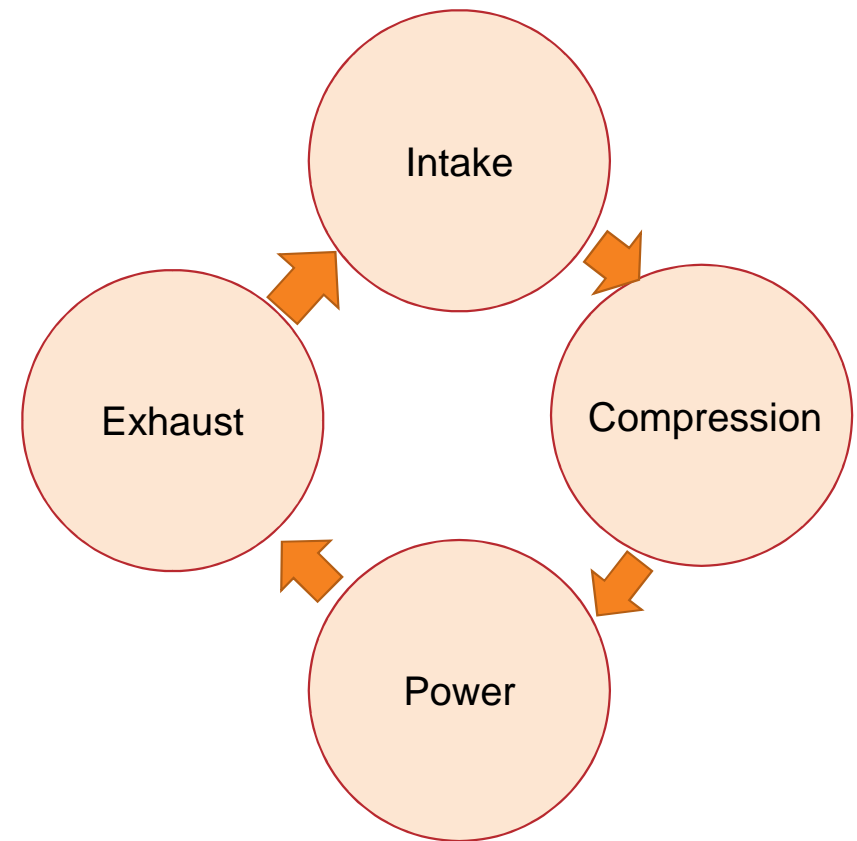
4-Stroke Stationary Natural Gas Engine

➤ Four Stroke

- Up to 7,000 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**

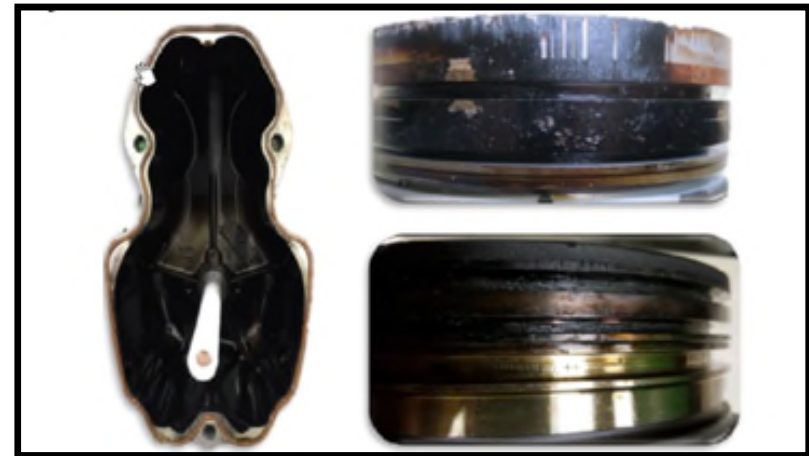
- Varnish (high temperature deposits)
- Siloxane (silicon compounds) from landfill gas

➤ **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

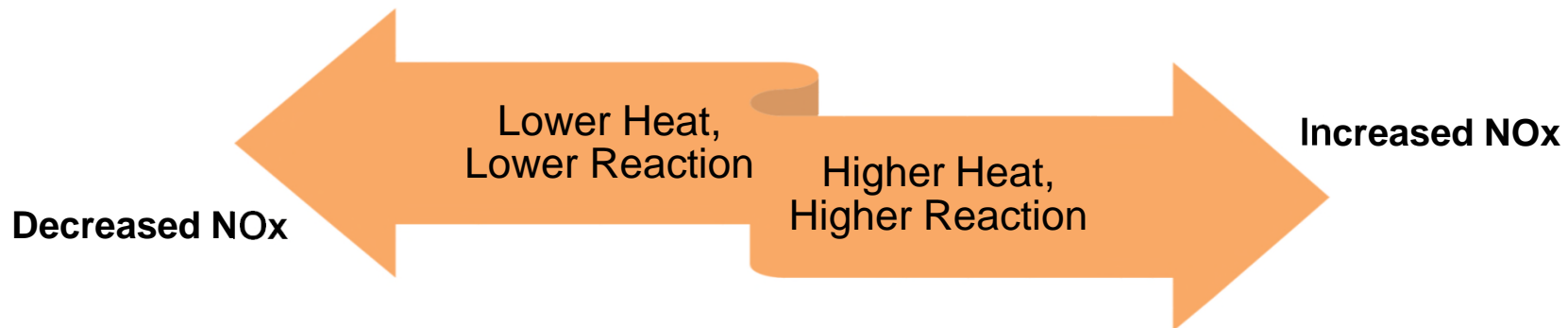
➤ Result

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

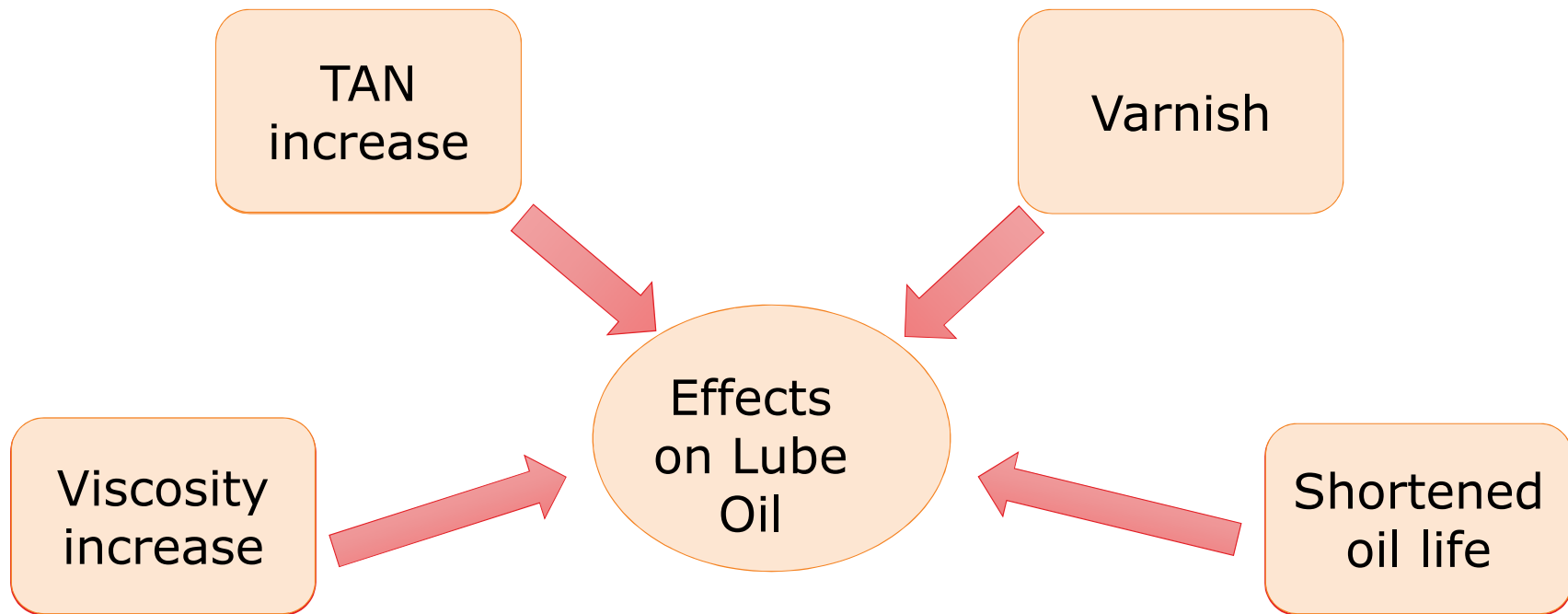
Nitration and Combustion Temperature

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

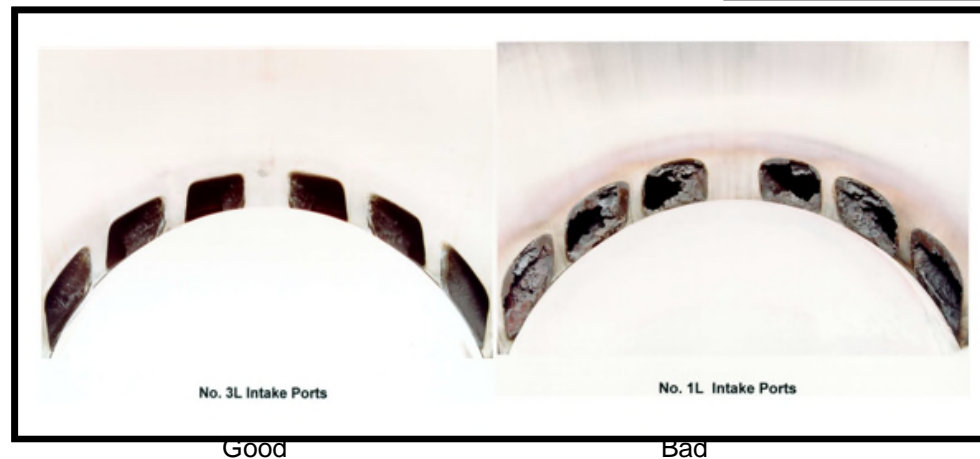


Nitration in Natural Gas Engines



2-Stroke Key Lubricant Performance Properties

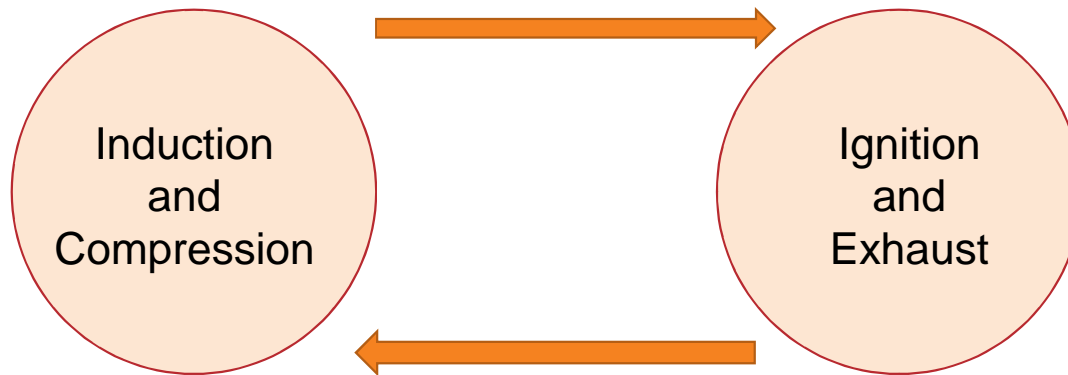
- Minimize Port and Chamber Deposits
- Keep Engine Parts Clean
- Reduce Wear
- Prevent Rust and Corrosion



Port Plugging

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

Current CITGO Pacemaker GEO 4-Stroke Products

PRODUCT	ASH	GAS	APPLICATIONS
Pacemaker GEO 1900XL	0.5	Sweet, Sour	High Nitration or Oxidation Conditions, Extended Oil Life Capable, Catalyst Compatible
Pacemaker GEO 1700	0.45	Sweet, Sour	High Nitration or Oxidation Conditions, Extended Oil Life Capable, Catalyst Compatible
Pacemaker GEO 1600	0.5	Sweet, Sour	Nitration or Oxidation Conditions, Extended Oil Life Capable, Catalyst Compatible
Pacemaker GEO 800	0.46	Sweet, Sour	High Nitration or Oxidation Conditions, Extended Oil Life Capable, Catalyst Compatible
Pacemaker GEO LFG LA	0.55	Sour, LFG, Biogas	High Oxidation Conditions, Extended Oil Life Capable, Catalyst Compatible
Pacemaker GEO 700	0.9	Sweet, Sour	High Oxidation Conditions, Extended Oil Life Capable
Pacemaker GEO 15SL	0.45	Sweet, LP	Irrigation Pump Service, Converted Gasoline Engines, Extended Oil Life Capable

New CITGO Pacemaker GEO 4-Stroke Products

PRODUCT	ASH	GAS	APPLICATIONS
Pacemaker GEO 1900XL	0.5	Sweet, Sour	High Nitration or Oxidation Conditions, Extended Oil Life Capable, Catalyst Compatible
Pacemaker GEO 1600	0.5	Sweet, Sour	Nitration or Oxidation Conditions, Extended Oil Life Capable, Catalyst Compatible
Pacemaker GEO 1400	0.5	Sweet, Sour	Nitration or Oxidation Conditions, Extended Oil Life Capable, Catalyst Compatible
Pacemaker GEO LFG LA	0.55	Sour, LFG, Biogas	High Oxidation Conditions, Extended Oil Life Capable, Catalyst Compatible
Pacemaker GEO 700	0.9	Sweet, Sour	High Oxidation Conditions, Extended Oil Life Capable
Pacemaker GEO 15SL	0.45	Sweet, LP	Irrigation Pump Service, Converted Gasoline Engines, Extended Oil Life Capable

Current CITGO Pacemaker GEO 2-Stroke Products

PRODUCT	ASH	GAS	APPLICATIONS
Pacemaker GEO 1200	<u>Ashless</u>	Sweet	Extended Oil Life Capable, 4-Stroke Applications that Require <u>Ashless</u> GEO
Pacemaker GEO 1000	<u>Ashless</u>	Sweet	Extended Oil Life Capable

New CITGO Pacemaker GEO 2-Stroke Products

PRODUCT	ASH	GAS	APPLICATIONS
Pacemaker GEO 1000	<u>Ashless</u>	Sweet	Extended Oil Life Capable, 4-Stroke Applications that Require <u>Ashless</u> GEO



CITGO Pacemaker Gas Engine Oil

Low Ash Gas Engine Oil

Pacemaker GEO 1900XL Series

- Unsurpassed performance in severe nitration & oxidation application
- Enhanced extended drain capability
- SAE 30, 40 and 15W-40
- Low pour point

Pacemaker GEO 1600 Series

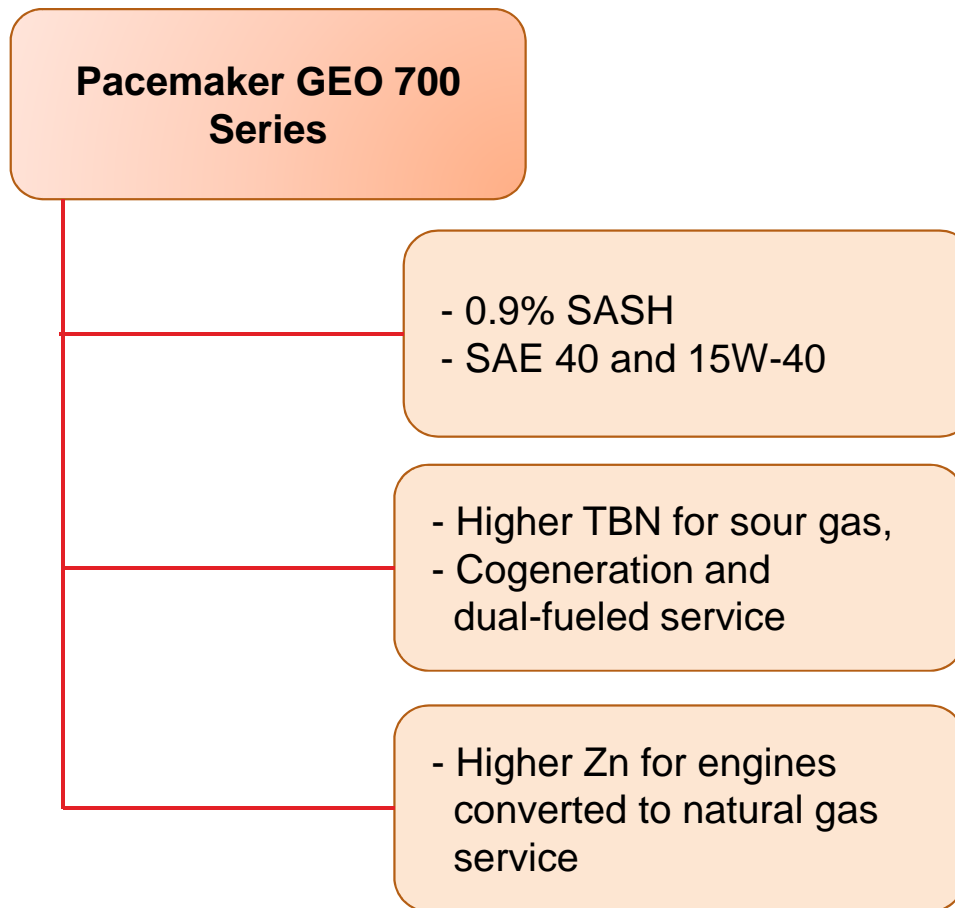
- Enhanced extended drain capability
- Oxidation and nitration condition
- SAE 30, 40 and 15W-40
- Low pour point

Pacemaker GEO 1400 Series

- Enhanced extended drain capability
- Oxidation and nitration condition
- SAE 30, 40 and 15W-40
- Low pour point

CITGO Pacemaker Gas Engine Oil

Mid Ash Gas Engine Oil



CITGO Pacemaker Gas Engine Oil

Ashless Gas Engine Oil

**Pacemaker GEO 1000
Series**

- Premium Performance
- Extended oil life capable
- 4-cycle applications that require ashless GEO
- Uncommon SAE 30/40, 15W-40 and SAE 40
- Low pour point

CITGO Pacemaker Gas Engine Oil

Specialty Gas Engine Oil

Pacemaker LFG LA 40

- New generation low ash gas engine oil for landfill and digester gas service

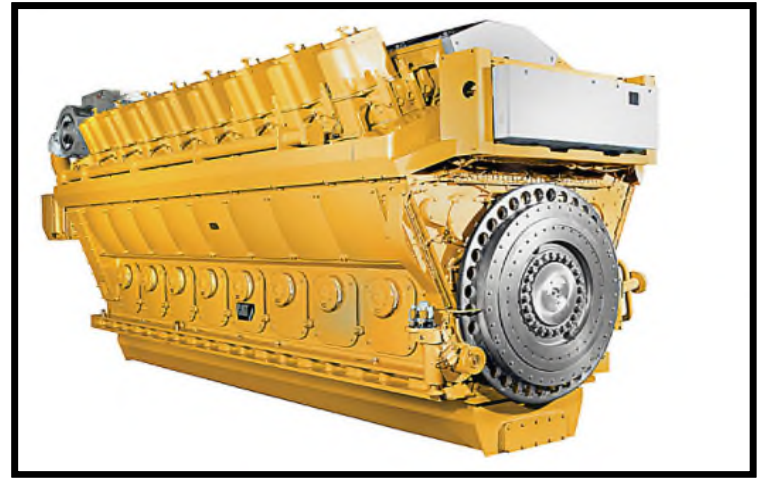
Pacemaker GEO 15SL

- Full synthetic, high Zn for engines converted to natural gas service

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



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

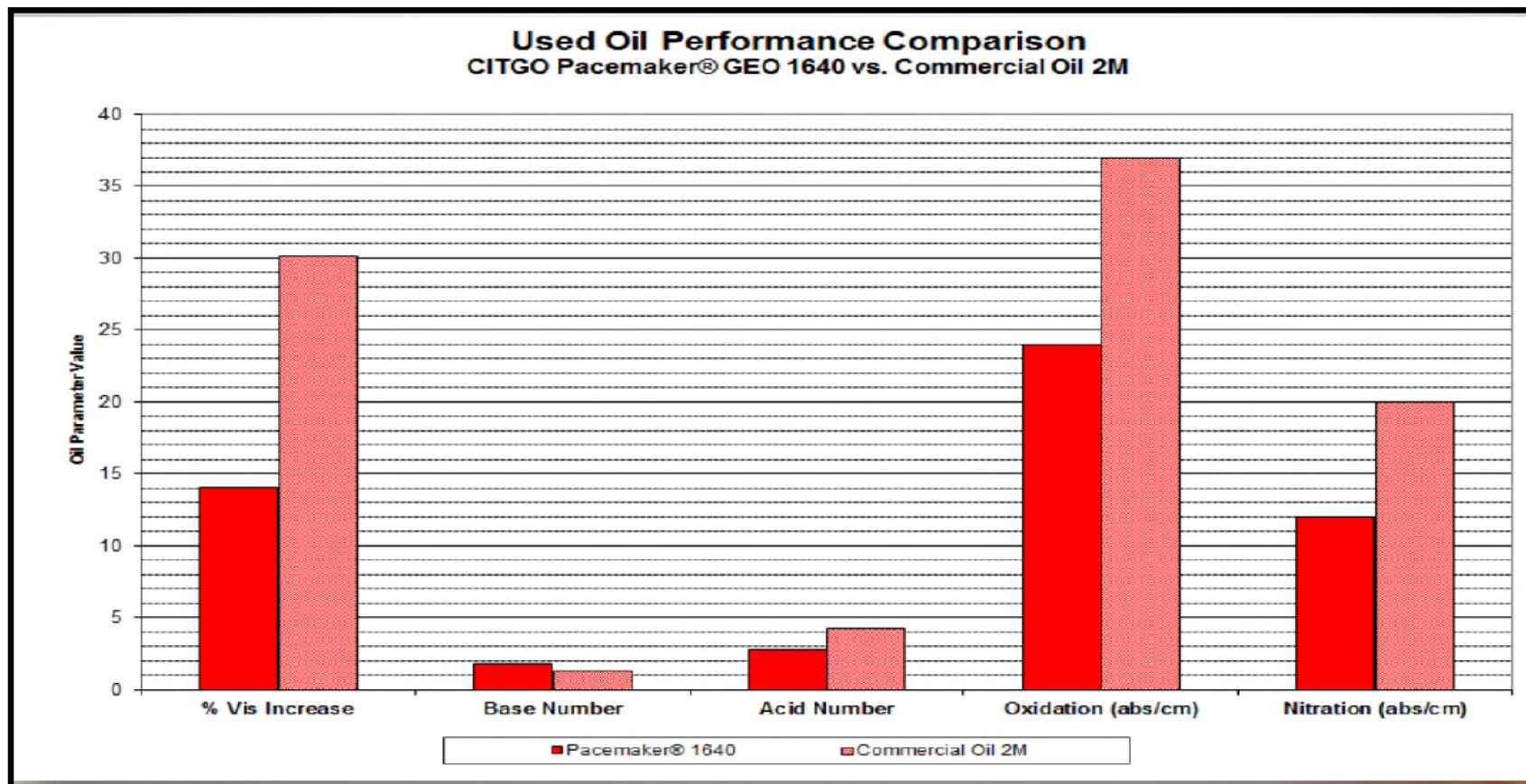
CITGO Pacemaker GEO 1640

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

November 12, 2021

Automatic Transmission Fluids

November 19, 2021

Clarion Environmental Products

December 3, 2021

ISO Cleanliness Requirements

December 17, 2021

Railroad Industry Products
