The Feasibility of Fill-for-Life Turbine Oils

Greg Livingstone
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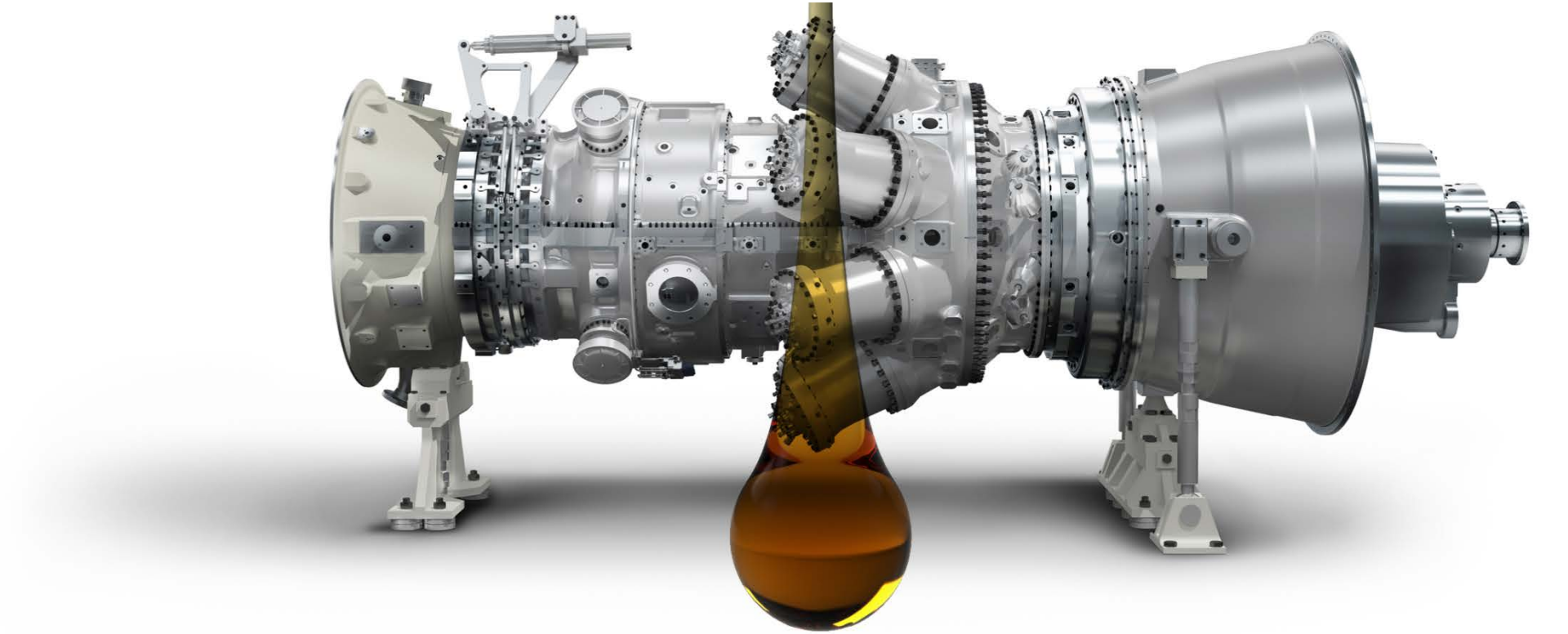


Outline

- How long is Fill-for-Life anyway?
- Bleed & Feed Strategy
- Why do Turbine Oils Fail?
- Replenishing Antioxidants:
  1. Feasibility
  2. Qualification & Compatibility
  3. Long-term performance
- Summary

What is the Life of Power Plants?

- Coal-Fired Power Plant were designed to last 30 years, however in practice they last much longer
  - Average age of a coal plant in the US is 38 years old
  - Average age of a retiring coal plant is 50 years old
- NGCC plants are also designed to last 30 years
  - Also expected to last longer
- Nuclear Power Plants were designed to last 40 years
  - Through re-licensing, most nuclear power plants will last longer

Average Age of Turbine Oil?

	Hydro	Steam	Gas
Critical turbine components	bearings guide vanes control system	bearings control system	bearings gears control system
Speeds, rpm	50-600	>3,000	3000-7,000
Oil sump temp., °C	40-60	40-70	50-95
Hot spot peaks, °C	75-90	80-150	150-280
Unfavorable impact	(water) Air	(steam) Air	air high temp.
Oil Life (Years)	**20+**	**10-20+**	**6-10**

Fill-For-Life Objective

- Allow a turbine oil to operate for 40 years without performance problems and within condemning limits
- No flushes, confined space tank cleaning or oil reclamation
- No bleed & feeds

What is the End of Life?

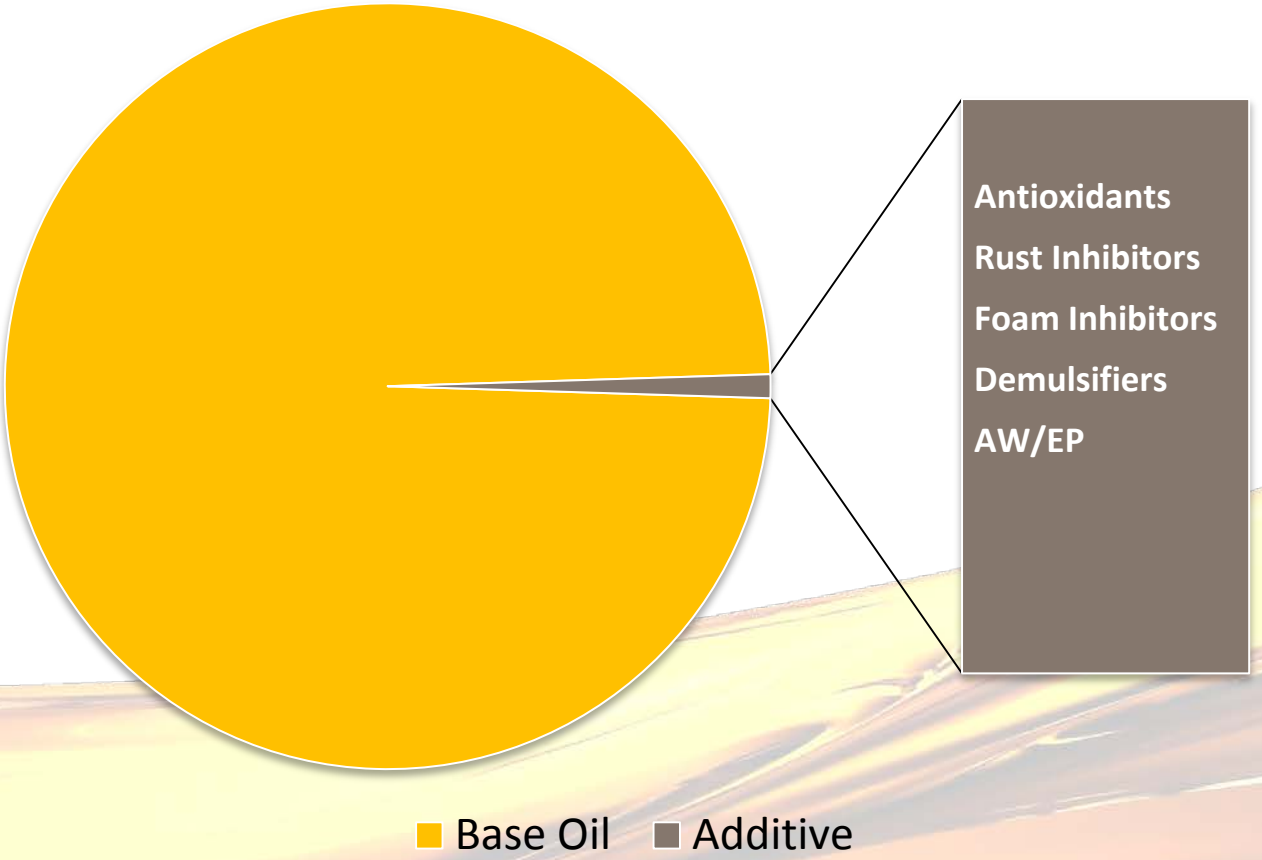
ASTM D4378 suggests the end of turbine oil life is when there are 25% remaining antioxidants.

RULER (ASTM D6971) is the preferred test for this, however RPVOT (ASTM D2272) is still commonly used.

Options for oils with low AO levels

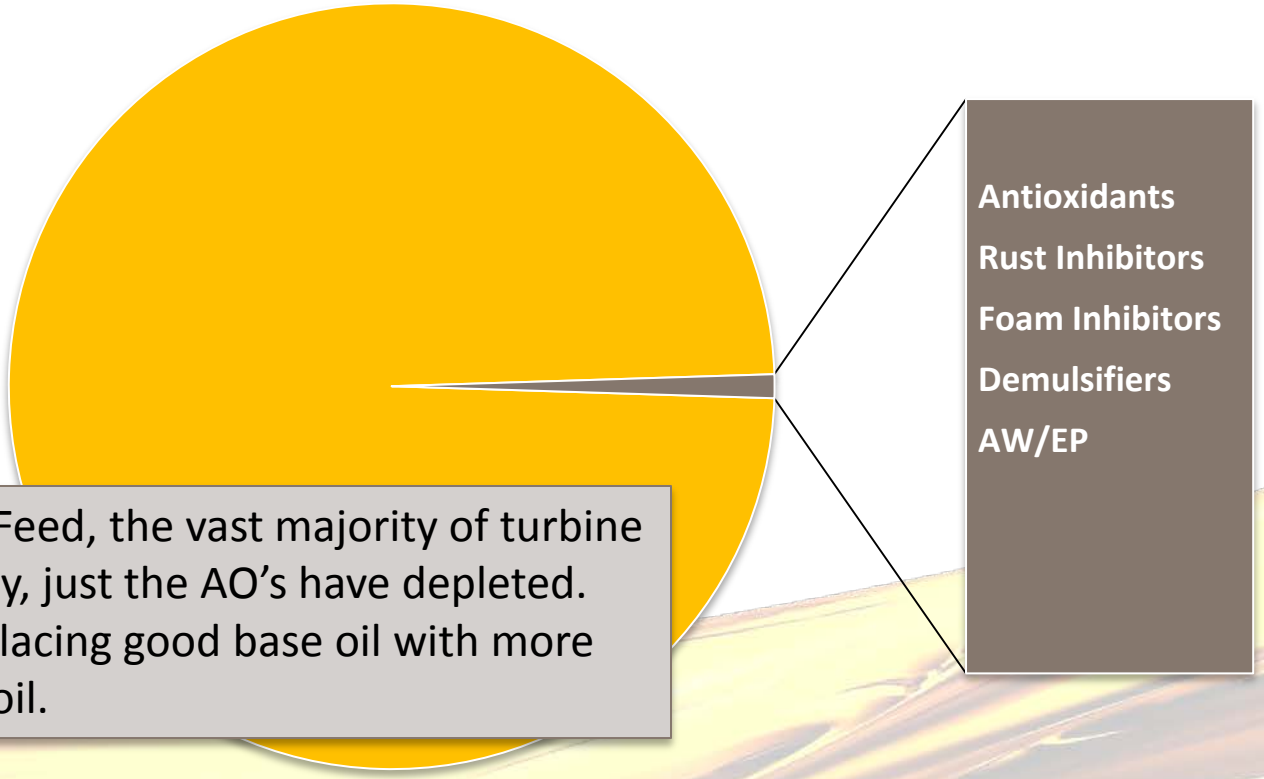
BLEED & FEED IS UNECONOMICAL

R&O Formulations



Ref: Livingstone, Wooton

R&O Formulations



In Bleed & Feed, the vast majority of turbine oil is healthy, just the AO's have depleted. You are replacing good base oil with more good base oil.

Ref: Livingstone, Wooton

Gas Turbine Bleed & Feed Case Study

6,000 gallon reservoir
Plant performed a 12% Bleed & Feed

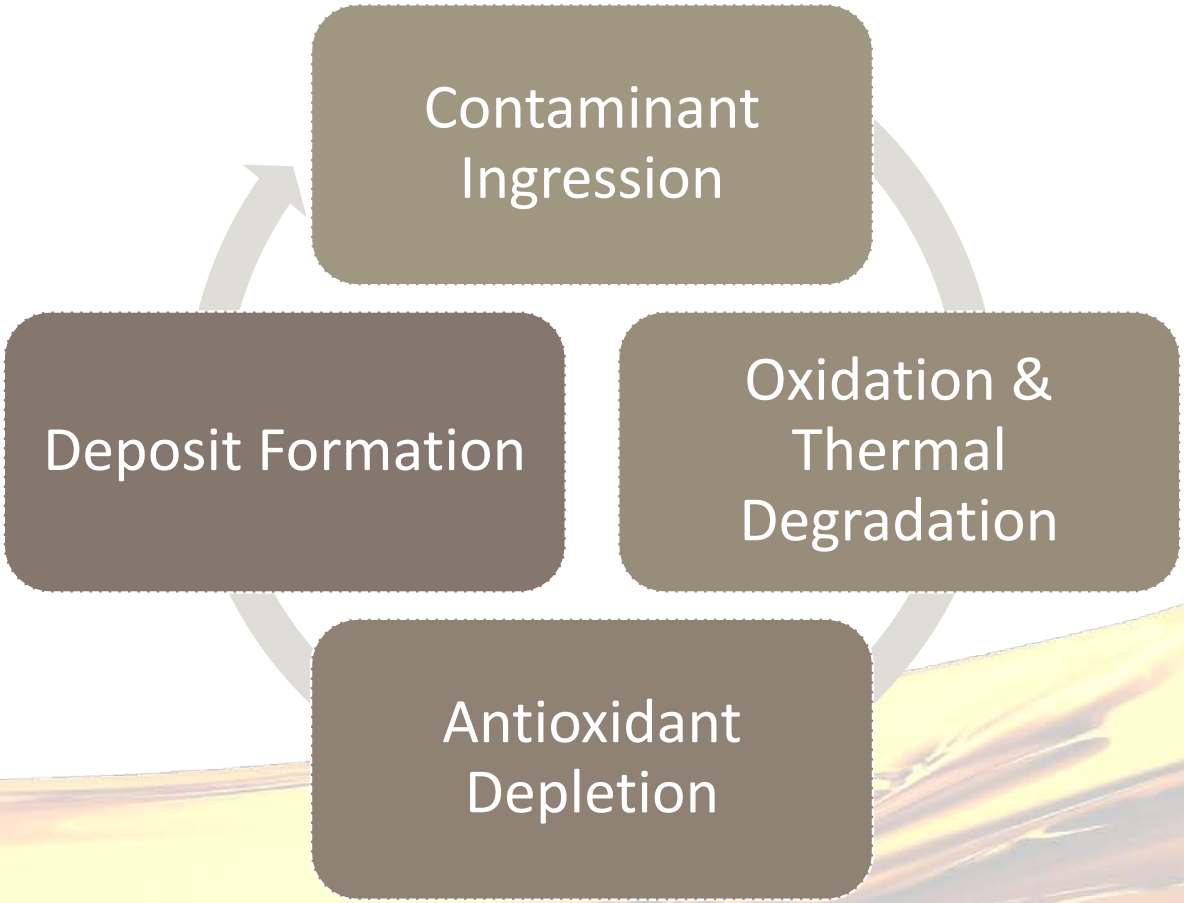
Test	Before Bleed & Feed	Estimated Results of Bleed & Feed	Results of Bleed & Feed
Amines (%)	24	33	26
Phenols (%)	8	19	8

Degradation Products are Reactionary

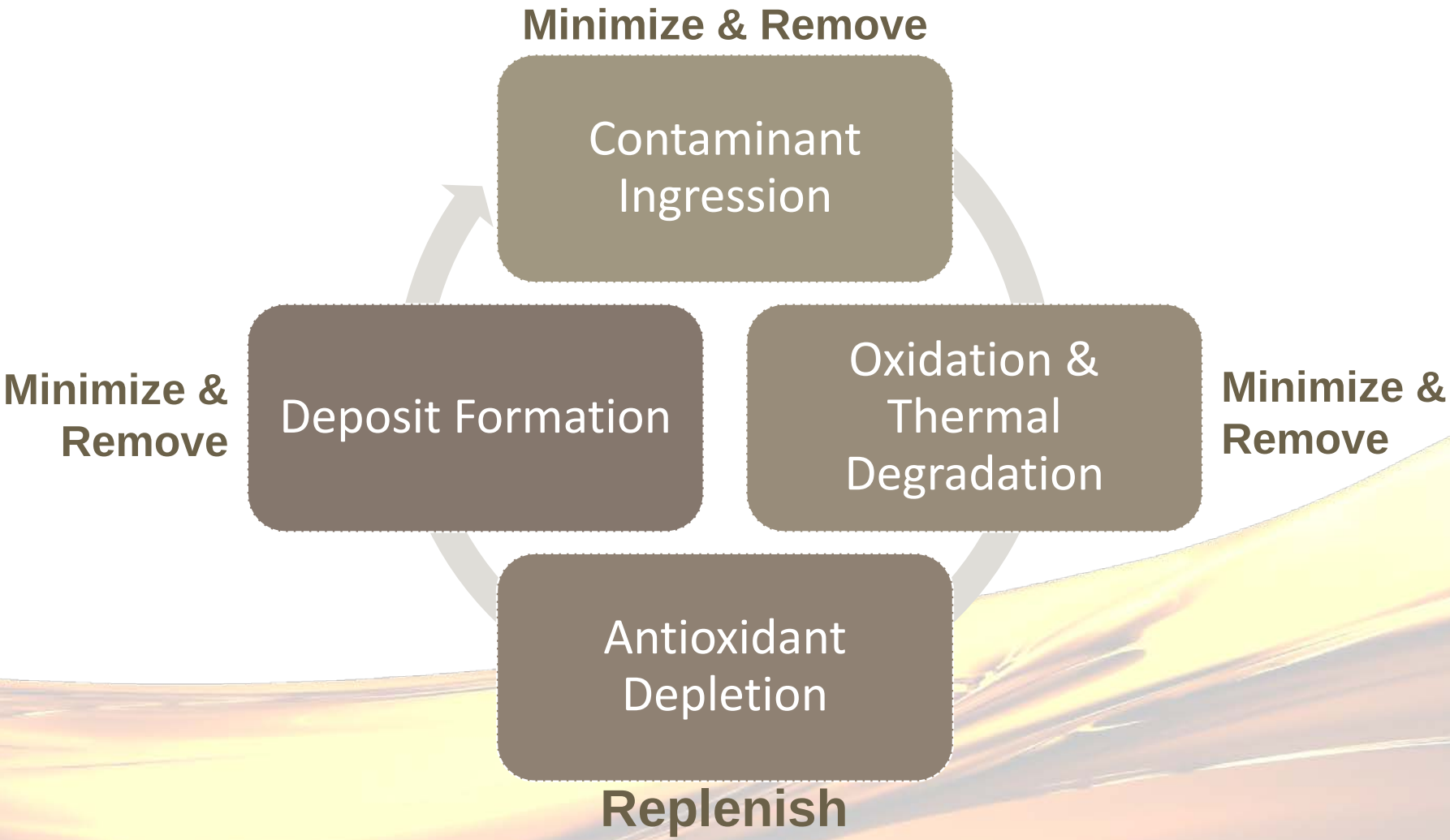
- Sludge and varnish are reactionary molecules that will quickly deplete fresh antioxidants
- This lowers the value of bleed & feed even further

Estimated cost for bleed & feed is 4X the price of new oil

How do Turbine Oils Degrade



Fill-for-Life Objectives



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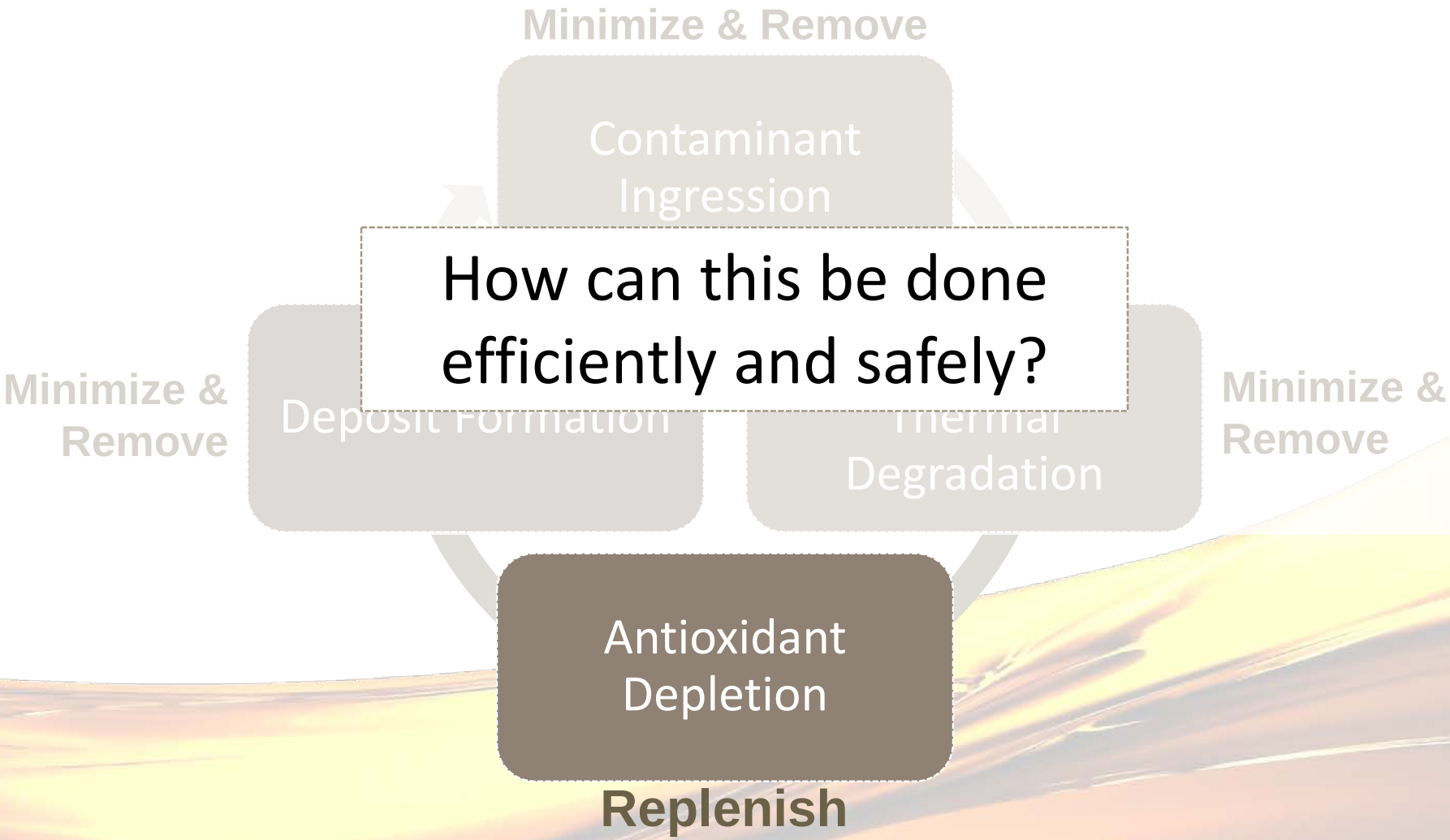


Criteria for Success

1. Antioxidants that are easy to add on-site without special blending equipment
2. Antioxidants must be compatible with in-service turbine oil and not cause any adverse reactions
3. Antioxidants must be stable in the formulation and provide long-term performance.

ADDING ANTIOXIDANTS TO IN-SERVICE TURBINE OILS

Additive Concentrate

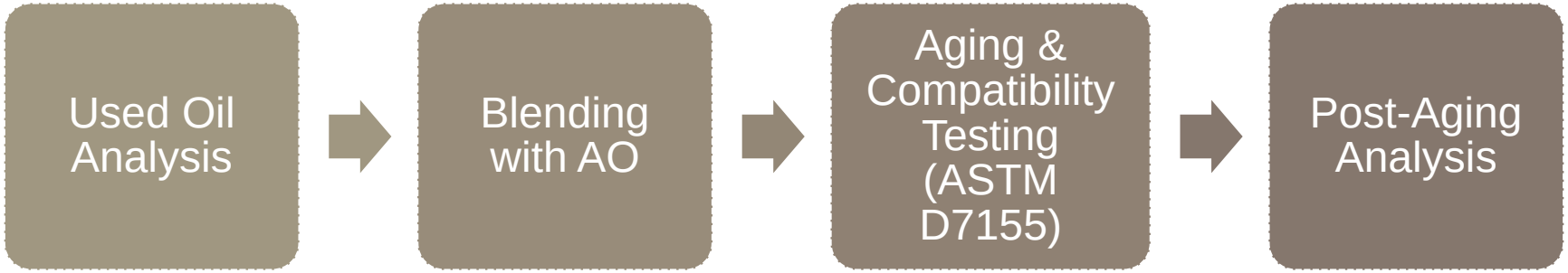
AO’s must be blended into a soluble concentrate that can be easily dispensed into the turbine reservoir without any special equipment.

DETERMINING CANDIDACY FOR ANTIOXIDANT REPLENISHMENT

Adding AOs to In-Service Turbine Oils

- It is critical to have a formulator intimately familiar with antioxidant chemistries.
- Antioxidant formulations are “balanced”. It is important to “re-balance” the formulation.
- The carrier fluid must be compatible with the in-service oil.
- Antioxidant types and treat rates depend upon the original oil formulation and current oil condition.
- Up-front testing is necessary to predict results.

In-Service Oil Qualification Testing



Appearance
Ruler
MPC
Demulsibility
Foam
Viscosity
TAN
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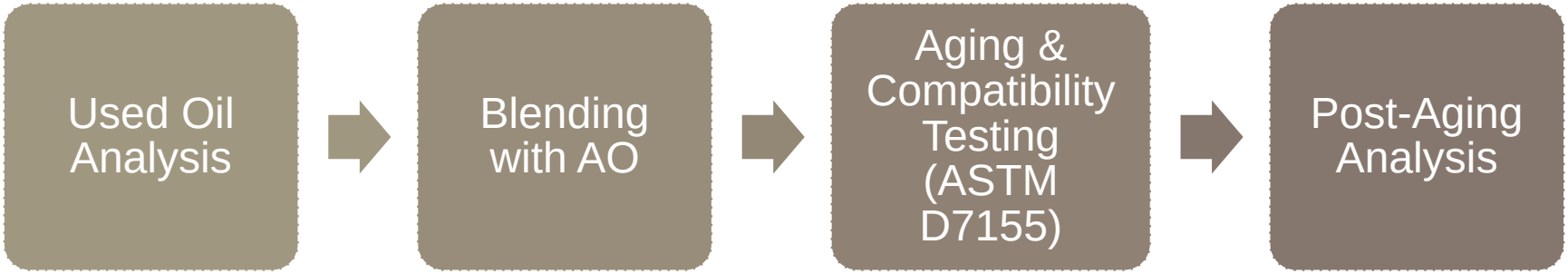

Appearance
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Air Release

1. No Negative Impacts
2. Significant AO response

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Qualified Oil

	Used Oil	UO + Boost AO
Compatibility of mixture, ASTM D7155		
Fluid Clarity, rating/description	1	1
Sediment, rating/description	0	0
Result, pass/fail	Pass	Pass
Water Content, ASTM D6304, ppm	18	15
Ruler, ASTM D6971		
Area Amminic:	4615 (33%)	29589 (215%)
Area Phenolic:	0	0
Membrane Patch Colorimetry, ASTM D7843		
ΔE	39	6
Weight of Residue, mg/L	196	52

Qualified Oil

	Used Oil	UO + Boost AO
Demulsibility @ 54°C, ASTM D1401		
Oil-Water-Emulsion/Time	24-27-31/30	42-35-5/30
Foaming Characteristics, ASTM D892		
Sequence I, ml foam/time to break	240/0-184	170/0-116
Viscosity, ASTM D445		
100°C Viscosity, cSt	5.51	5.44
40°C Viscosity, cSt	33.19	32.62
Viscosity Index	101	100
TAN, ASTM D664, mg/KOH	0.17	0.18
RPVOT, ASTM D2272, minutes	199	893

Failing Qualification Test

	Used Oil	UO + Boost AO
Fluid Clarity, rating/description, ASTM D7155	1	**3**
Sediment, rating/description	0	0
Result, pass/fail	Pass	**Fail**
RULER, Area Amminic:	2453	2313
RULER, Area Phenolic:	2754	12014
Membrane Patch Colorimetry, ΔE	16	**31**
Weight of Residue, mg/L	26	**86**
Demulsibility @ 54°C, ASTM D1401	40-40-0/15	40-40-0/15
Foaming Characteristics, ASTM D892	530-0-589	530-0-585
100°C Viscosity, cSt, ASTM D445	7.02	6.9
40°C Viscosity, cSt, ASTM D445	46.49	45.1
Viscosity Index	108	108
TAN, ASTM D664, mg/KOH	0.11	0.09
RPVOT, ASTM D2272, minutes	622	**589**

Failing Qualification Test

		UO + Boost AO
Fluid Clarity, ra		3
Sediment, rati		0
Result, pass/fa		Fail
RULER, Area A		2313
RULER, Area P		12014
Membrane Pat		31
Weight of Resi		86
Demulsibility (		40-40-0/15
Foaming Chara		530-0-585
100°C Viscosity		6.9
40°C Viscosity,		45.1
Viscosity Index		108
TAN, ASTM D6		0.09
RPVOT, ASTM D2272, minutes	622	589

Photo of Oil Before & After Test

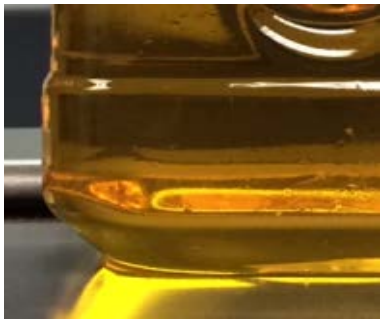


Photo of Patch Before & After Test

Compatible yet Unqualified

	Used Oil	UO + Boost AO
Fluid Clarity, rating/description, ASTM D7155	1	1
Sediment, rating/description	0	0
Result, pass/fail	Pass	Pass
RULER, Area Amminic:	5656	13278
RULER, Area Phenolic:	2083	1551
Membrane Patch Colorimetry, ΔE	33	31
Weight of Residue, mg/L	84	103
Demulsibility @ 54°C, ASTM D1401	10-15-55/30	10-10-60/30
Foaming Characteristics, ASTM D892	280/0-151	300/0-175
100°C Viscosity, cSt, ASTM D445	5.25	5.14
40°C Viscosity, cSt, ASTM D445	31.51	31.14
Viscosity Index	95	90
TAN, ASTM D664, mg/KOH	0.07	0.07
RPVOT, ASTM D2272, minutes	443	529

Compatible yet Unqualified

	Used Oil	UO + Boost AO
Fluid Clarity, rating/description, ASTM D7155	1	1
Sediment, rating/description	0	0
Result, pass/fail	Pass	**Pass**
Demulsibility @ 54°C, ASTM D1401	10-15-55/30	10-10-60/30
Foaming Characteristics, ASTM D892	280/0-151	300/0-175
100°C Viscosity, cSt, ASTM D445	5.25	5.14
40°C Viscosity, cSt, ASTM D445	31.51	31.14
Viscosity Index	95	**90**
TAN, ASTM D664, mg/KOH	0.07	0.07
RPVOT, ASTM D2272, minutes	443	**529**

Antioxidant package wasn't "rebalanced", therefore Boost AO is not recommended.

ASSESSING LONG-TERM PERFORMANCE OF ADDING AO

Measuring Long-Term Performance

1. Field Trials
   – Realistic results however may take 10 years

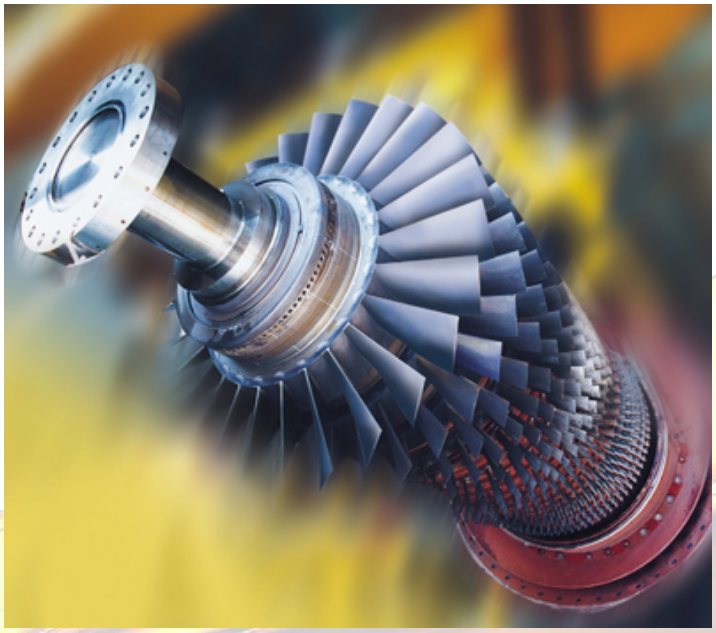
2. Laboratory Stress Tests
   – Needs to be correlated to field tests

Turbine Oil Performance Predictor

- The TOPP test was developed as a stress test to predict how turbine oils will perform in the field.
- Dozens of new oil samples have been stressed in the TOPP test
- Shows a wide range of performance with new turbine oils

Turbine Oil Performance Predictor (I)

- Test results have been correlated to in-service turbine oils.
- The test approximates 6 years of life in a large frame gas turbine
- The test approximates 9 years of life in a steam turbine



TOPP Test Parameters

Test Parameters

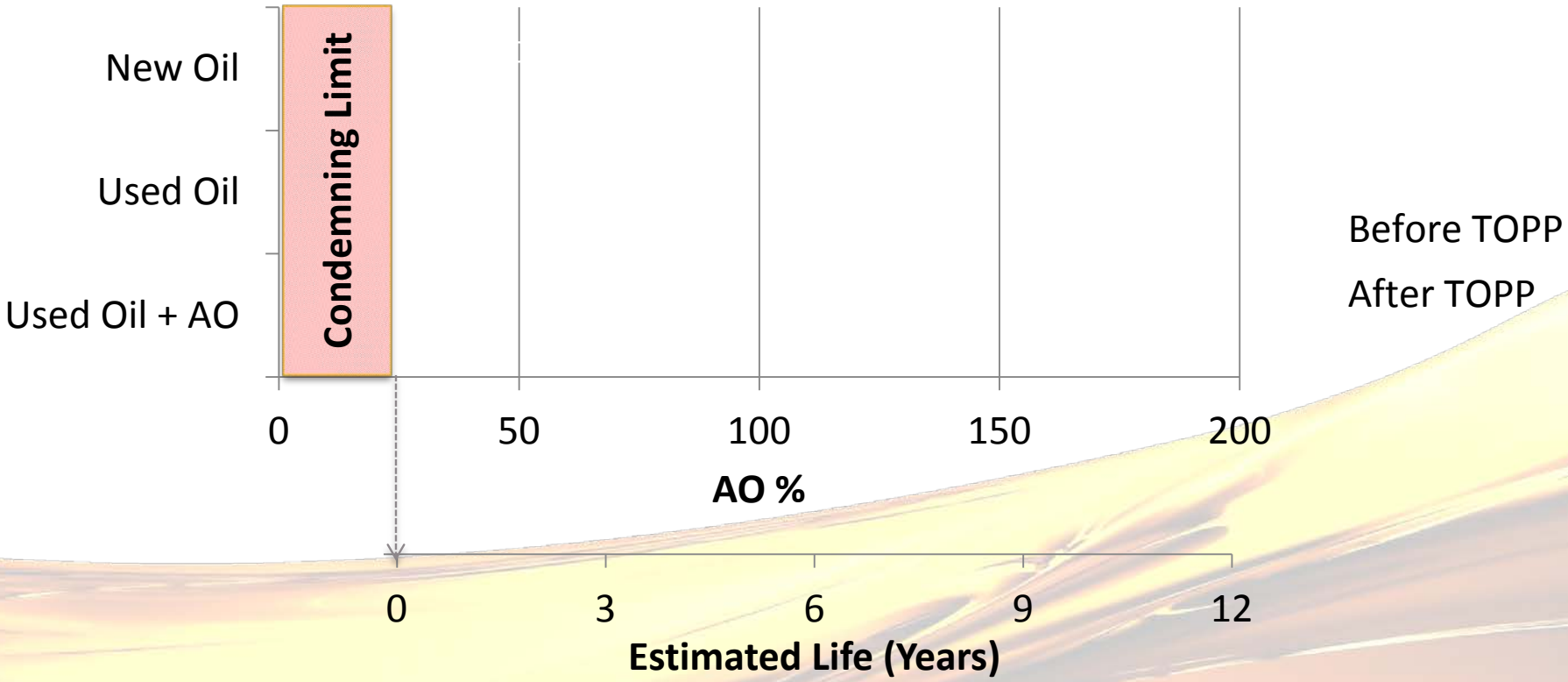
Turbine oil is maintained in a bath at 120^{o}C with an iron catalyst 6 weeks.

Common weekly tests are:

- MPC
- RULER
- RPVOT
- FTIR
- Others can be added as desired

TOPP RESULTS WITH AO REPLENISHED TURBINE OIL

Results of TOPP Testing



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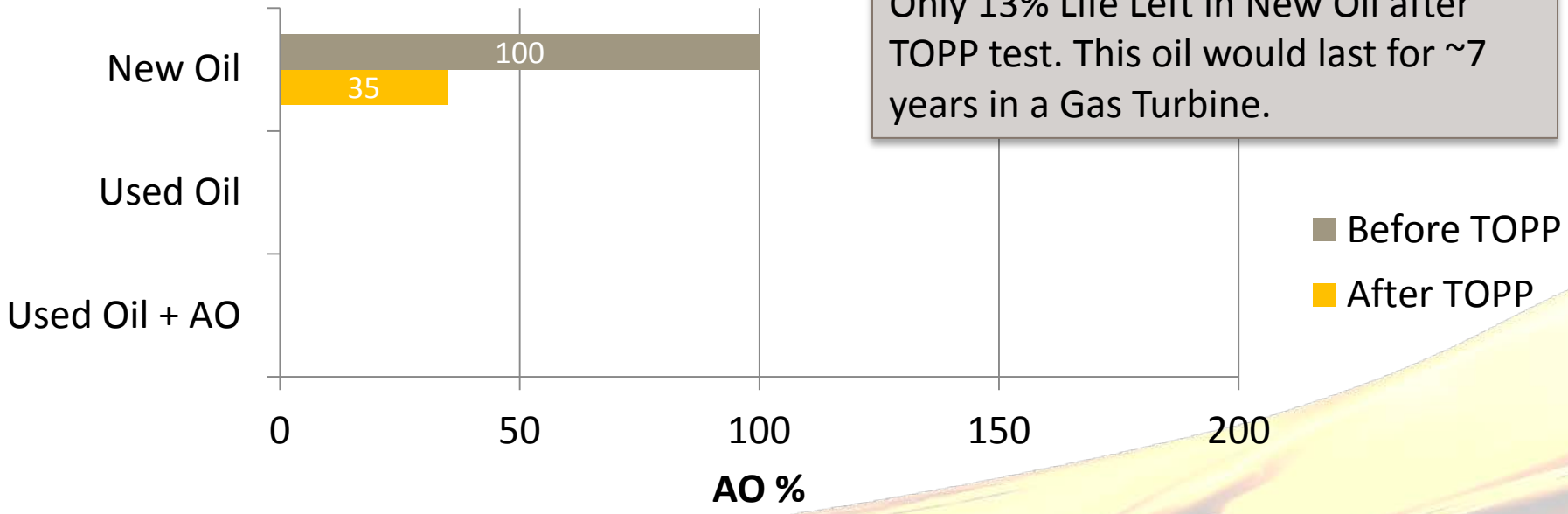

Only 13% Life Left in New Oil after TOPP test. This oil would last for ~7 years in a Gas Turbine.

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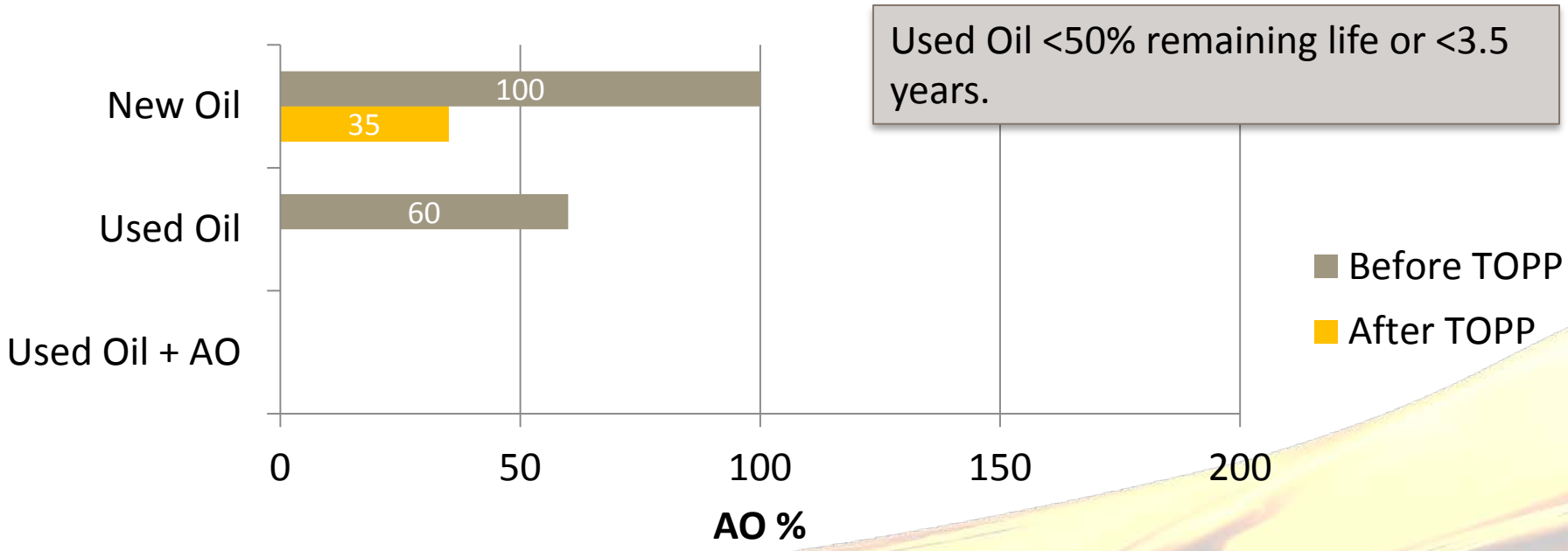

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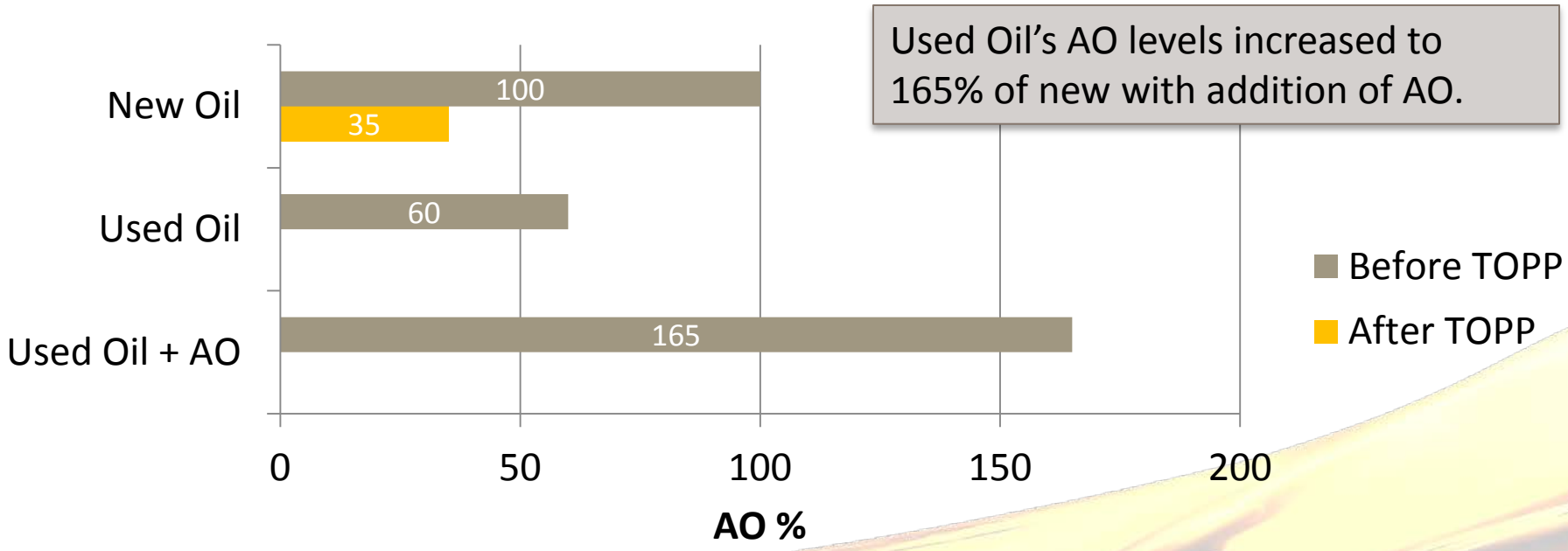

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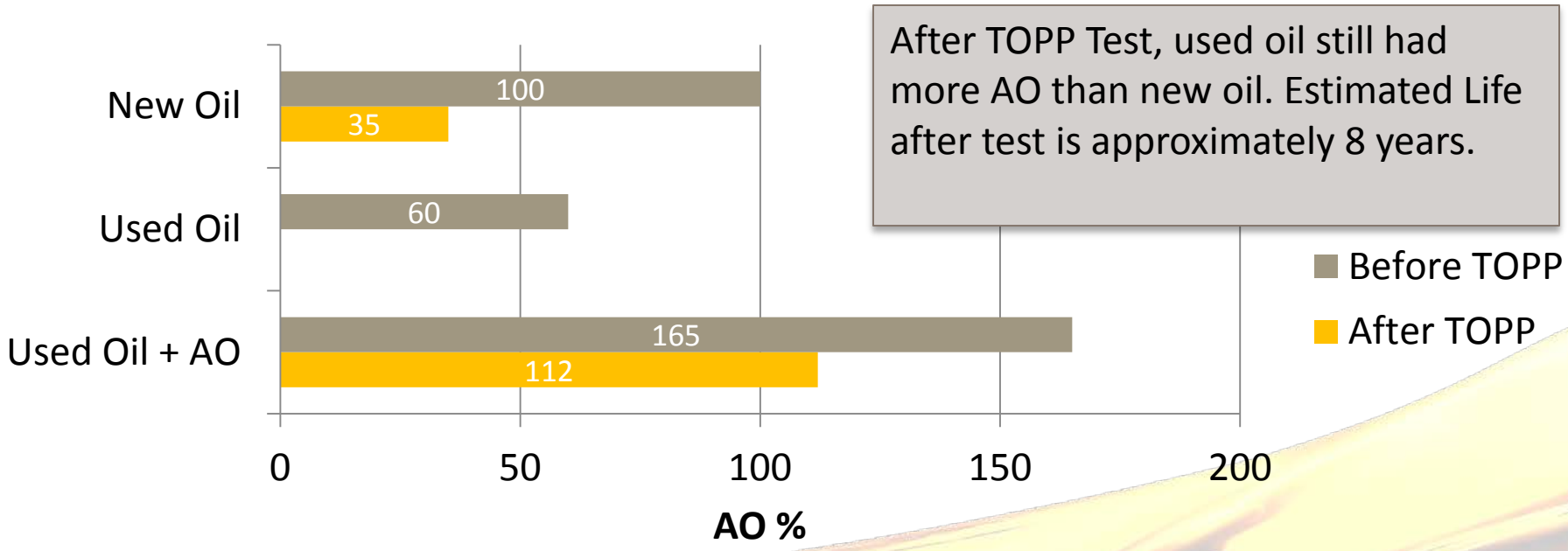
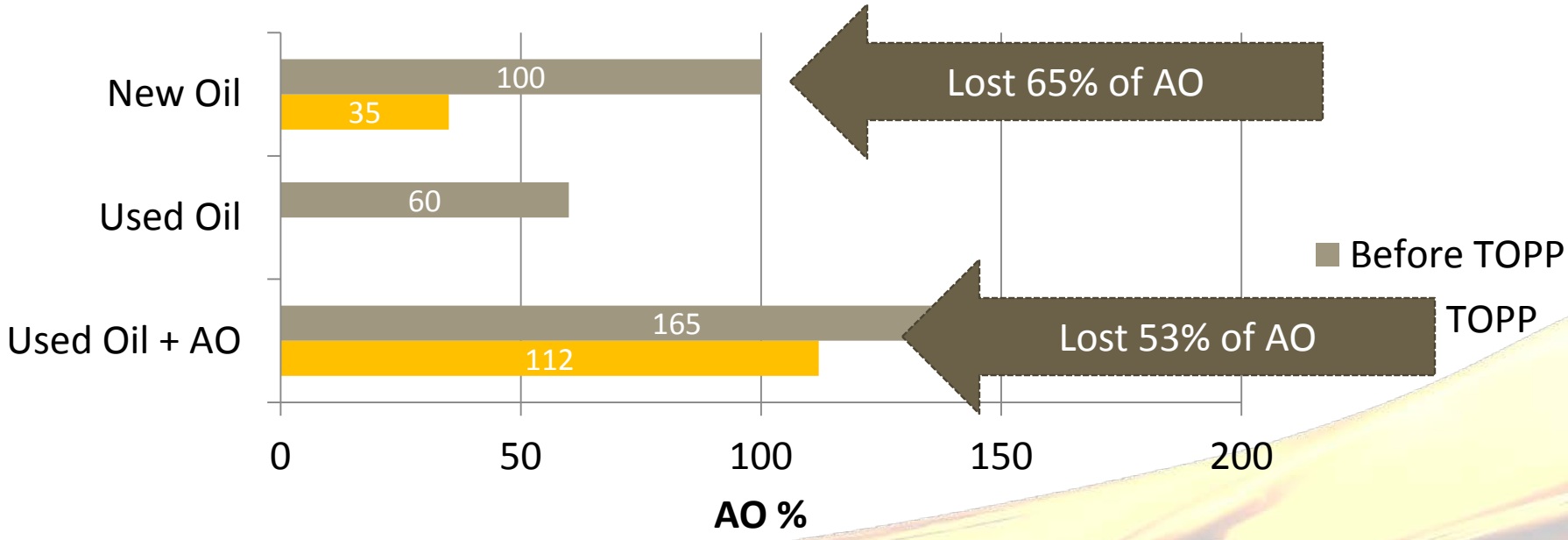


After TOPP Test, used oil still had more AO than new oil. Estimated Life after test is approximately 8 years.

Results of TOPP Testing



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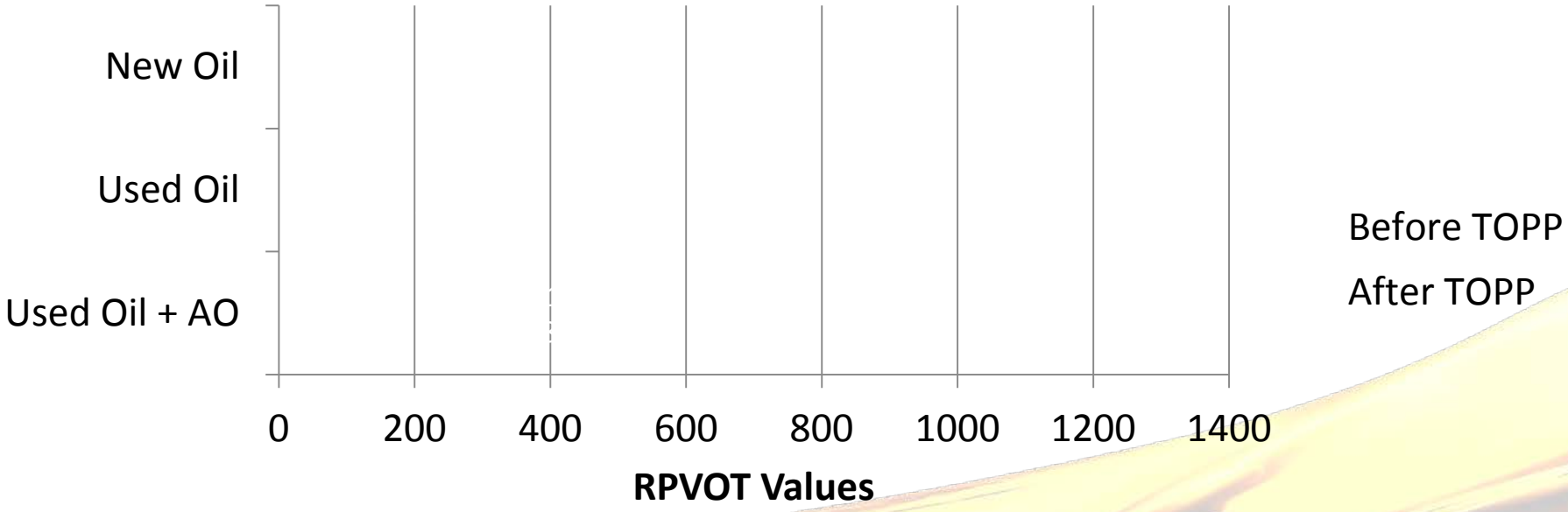
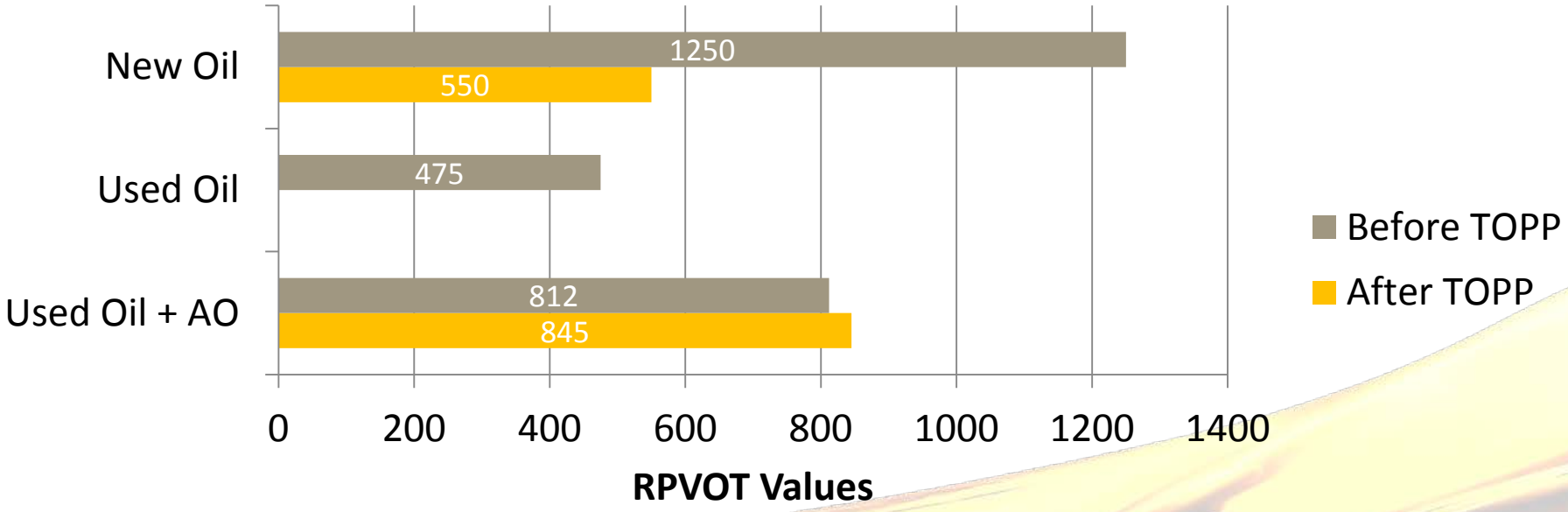


It is well accepted that initial RPVOT values do not correlate to the life and performance of turbine oils. “RPVOT retention” is a more important consideration.

Results of TOPP Testing



It is well accepted that initial RPVOT values do not correlate to the life and performance of turbine oils. “RPVOT retention” is a more important consideration.

4-YEAR FIELD TEST RESULTS

Large Frame GT Case Study

- 4 year old oil in a large frame GT
- Oil was maintained in excellent condition
- AO was added to the fluid in 2010.

Current Oil Condition

	Mar 2010 Before AO	Mar 2010 After AO	Dec 2014
Ruler, ASTM D6971, Amines(%)	60%	181%	128%
Membrane Patch Colorimetry, ASTM D7843	8	5	6
RPVOT, ASTM D2272, minutes	475	865	979

Similar AO depletion rates as seen in the TOPP test. Excellent RPVOT retention.

Case Study Summary

- Field test results demonstrate similar AO depletion compared to laboratory TOPP tests
- Part of the success of this project has been due to proactive actions by the plant
  - Use of a varnish mitigation system
  - Elimination of spark discharge problems
  - Excellent maintenance and condition monitoring program

SUMMARY

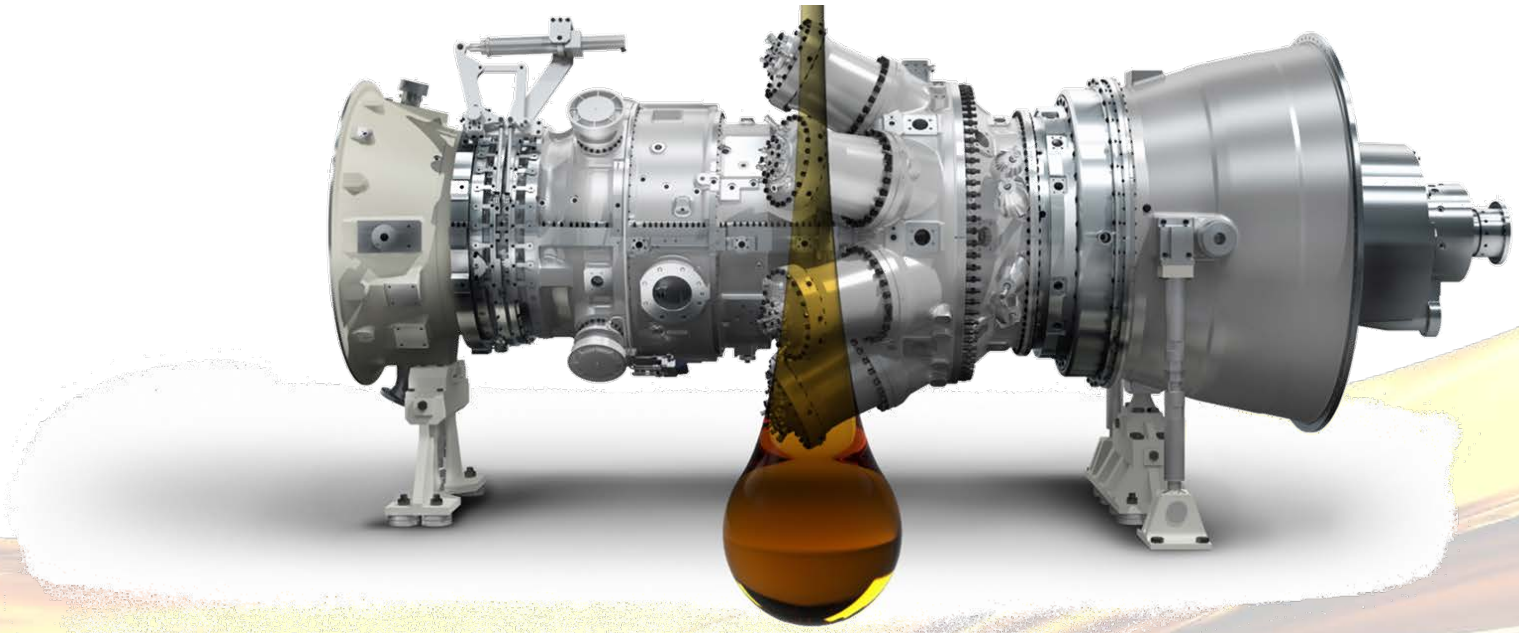
What's required for Fill-For-Life Turbine Oils?

- Fill-for-Life Turbine Oil - last for ~40 years, be maintained within spec and be problem free
- A key component of accomplishing this is replenishing depleted antioxidants
- In-situ antioxidant addition requires experience and expertise

Additive Replenishment Summary

- Up-front Qualification Testing is required prior replenishing antioxidants
- When an oil is qualified, in-situ AO addition provides excellent performance in laboratory stress tests (TOPP test)
- Field tests also show excellent performance and the results are similar to laboratory results
- The addition of antioxidants has been shown to at least double the life of in-service turbine oils.

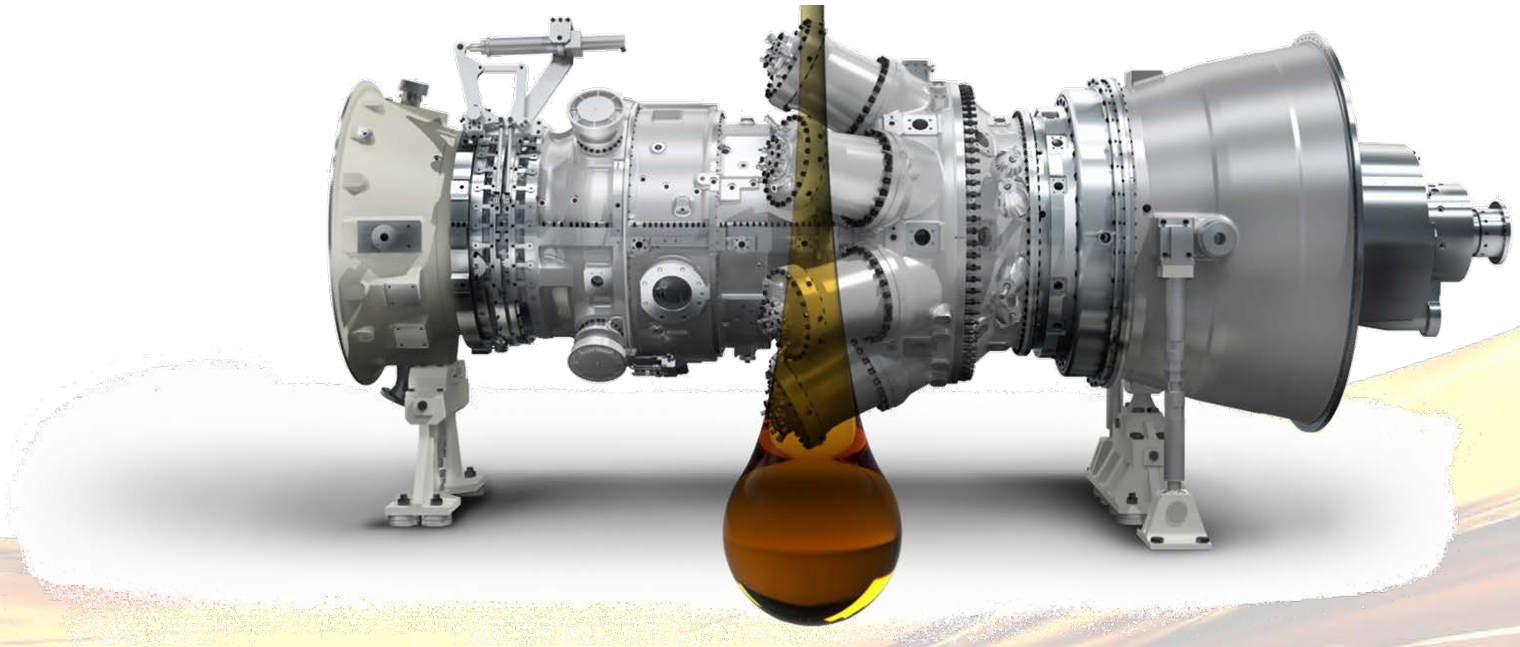
Is it Feasible to have a Fill-for-Life Turbine Oil?



Is it Feasible to have a Fill-for-Life Turbine Oil?

YES.

Are we there yet? **No.**



To realize Fill-For-Life Turbine Oils...

- Multiple antioxidant treatments needs to be further studied before Fill-For-Life becomes a reality
- Timing of AO replenishment is based on condition monitoring
- Removing oil degradation products and depleted antioxidants plays an important role in realizing fill-for-life turbine oils
- Prescribing the correct dose at the correct time is critical to achieve Fill-for-Life