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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

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PROTECTIVE COATINGS THAT MANUFACTURE THEMSELVES FOR HIGH PERFORMANCE APPLICATION | AMMTO

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This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project Overview

- This project is focused on developing a new class of lubricants that incorporate nanomaterials to enhance wear protection capabilities, thereby revolutionizing how machine components are maintained.
  - The technology being developed addresses a wide range of Department of Energy objectives related to sustainable manufacturing, including reducing costs, minimizing energy and material consumption, and mitigating the environmental impact of machine component production.
  - This project aims to overcome two main barriers:
    - First, developing a rapid coating deposition method to protect contact surfaces from wear and failure events
    - Second, identifying potential synergies and antagonisms between the nanocrystal and various lubricant additives
  - Although this technology can be utilized in various applications, it is being specifically developed for wind turbine (WT) gearboxes.

Project Outline

Innovation: Nanocrystal enhanced lubricant for superior wear protection of machine components

Project Lead: Pixelligent Technologies LLC

Project Partners: The University of Pennsylvania, Argonne National Laboratory, ExxonMobil Technology & Engineering Company, LANXESS Corporation

Timeline: 6/1/2020-8/31/2023, 90% complete

Budget:

	FY20 Costs	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$90,346.43	$581,056.10	$346,009.97	$144,430.50	$1,161,843.00
Project Cost Share	$28,272.65	$187,387.04	$141,058.98	$10,002.33	$366,721.00

End Project Goal: The objective of this project is to create nanocrystal enhanced film-forming lubricants (NFFLs) that can generate replenishing, thin film coatings to safeguard contact surfaces against “wear and tear” in wind turbine (WT) gearboxes.

Background & Strategic Approach

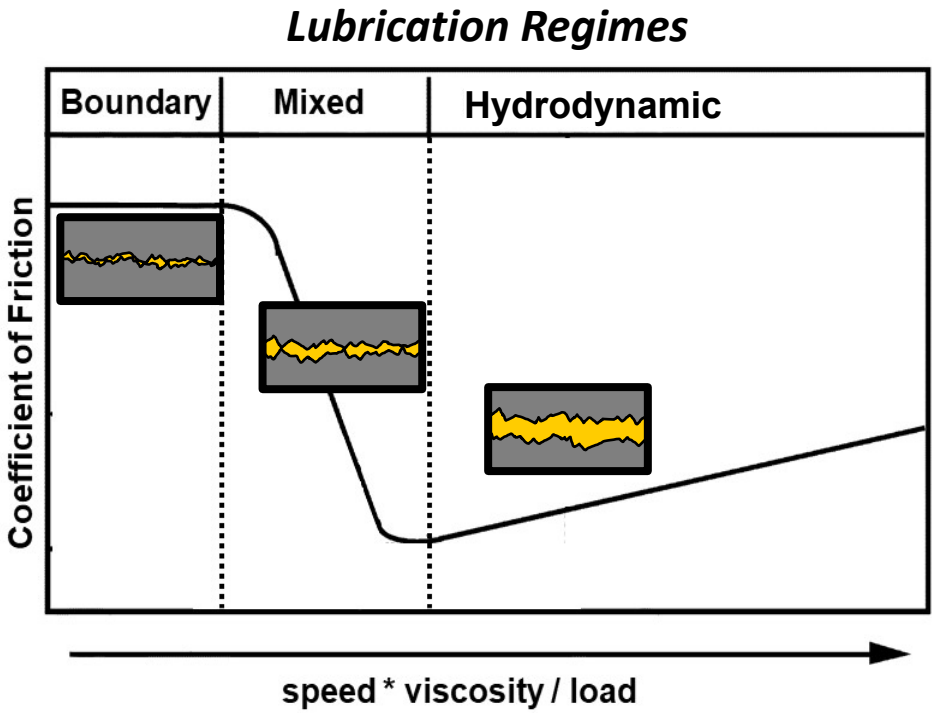
Motivation #1: Reduce premature failure in wind turbine (WT) due to harsh, varying contact conditions.

Operational & Maintenance (O&M) accounts for 25-30% of levelized cost of energy, representing $5B annual market in the United States.

Turbine Events	Resulting Contact Conditions	Induced Damage	ZrO_2 Solution
Torque reversals	Impact loads above yield	Surface denting, cracking damage	Soft, dampening tribofilm
Variable wind speeds	Sliding at bearings	Surface crack initiation, and smearing	Protection under high sliding, superior scuffing protection
Static charge collection/generator induced currents	Currents passing through contacts	Microstructural alterations and cracking	Insulating triboflm limiting current flow
Long periods of standstill and dithering	Slight contact motion, poor lubrication	Wear and surface damage accumulation	Robust film that can reform if worn away

Motivation #2: Improve energy efficiency by reducing viscosity of the lubricant.

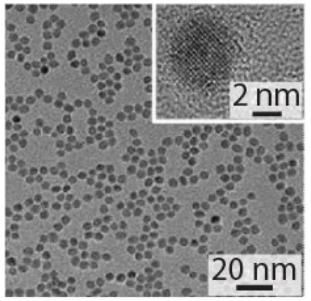
While lower viscosity lubricants can lead to fuel savings of up to 2.5%, they also carry the risk of increased wear and scuffing.



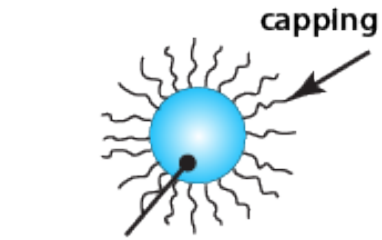
<u>The solution lies in the development of improved anti-wear and extreme pressure additives.</u>

Background & Strategic Approach

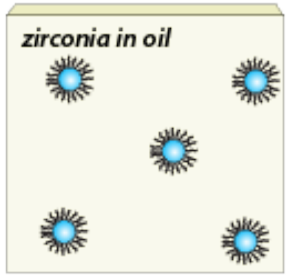
Nanocrystals as Tribofilm-forming Anti-wear Additives



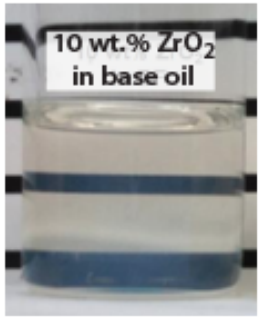
TEM image



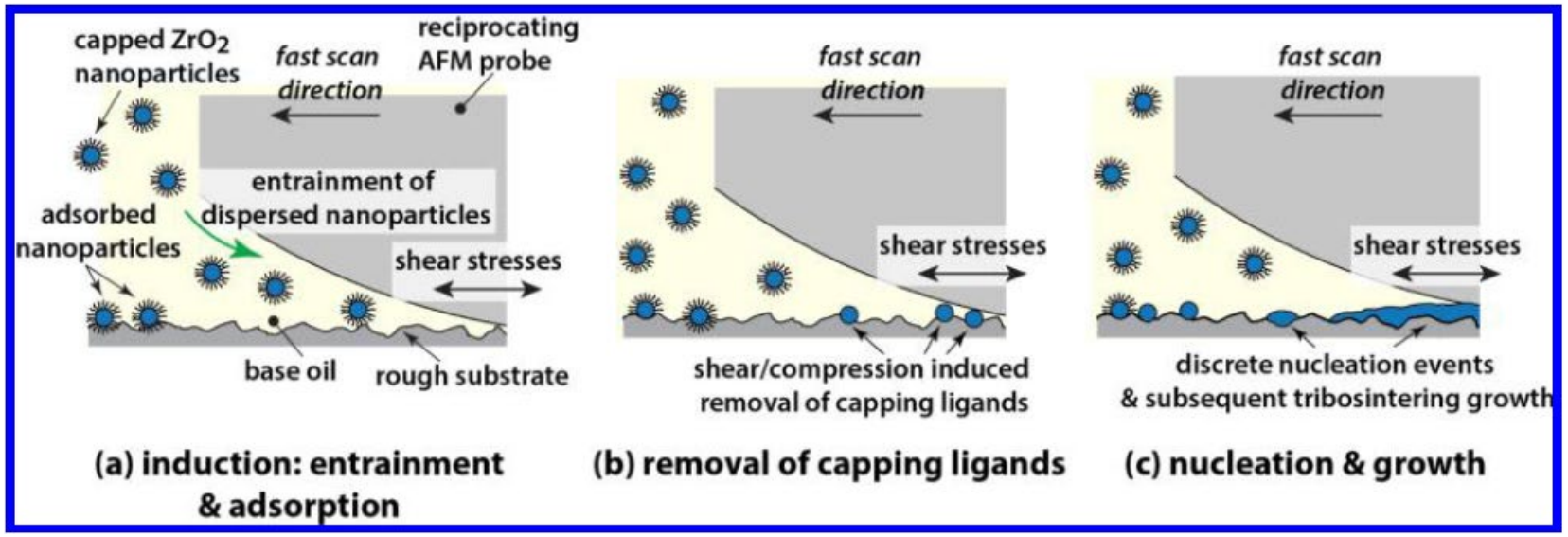
5nm zirconia nanoparticle



5nm zirconia nanoparticles are capped with dispersing ligands



Capping results in well dispersed, optically clear solutions in base stock



1. Entrainment of nanocrystals into contact
2. Shear-induced removal of capping ligands
3. Sintering of bare nanocrystals to form solid, surface-bound film
4. Coarsening (growth) of ZrO_2 grains

Background & Strategic Approach

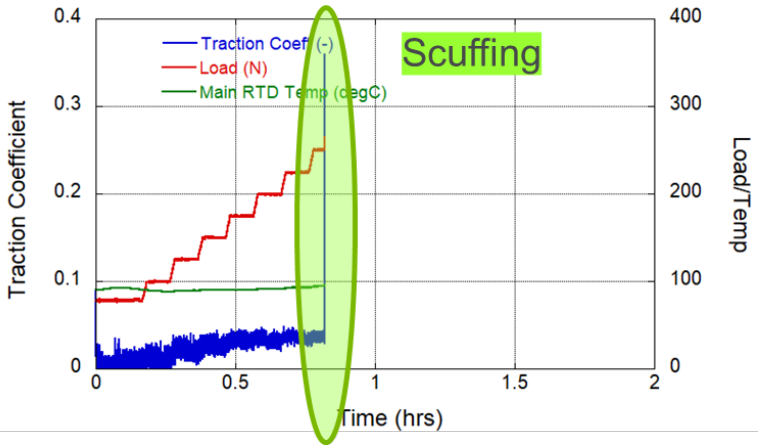
- Technical approach of this project:
  - Our current focus is on developing an alternative technology to replace traditional wear-resistant coatings like diamond-like carbon (DLC) and black oxide (BO) coatings.
  - Our method involves in-situ deposition of protective films at the contact zones of gears and rolling bearings, without requiring any specialized deposition equipment.
  - By adopting this approach, the equipment service life can be extended, resulting in reduced manufacturing and in-service replacement costs, as well as increased end-use energy efficiency.

- In our prior work, we (Pixelligent, UPenn, ANL) were able to demonstrate enhanced protection against scuffing, wear, and pitting in fully formulated commercial oils, through the addition of our proprietary technology.
- Our challenge was to enhance the understanding of the synergistic and antagonistic interactions between the nanocrystals and commonly used lubricant additives, with the goal of achieving superior performance.
- We have established a multidisciplinary team, comprising of academic partners (UPenn), national laboratories (Argonne National Laboratory), and industrial partners with expertise in lubricants (ExxonMobil), additives (LANXESS), and nanomaterials (Pixelligent), to collaborate on this project.

Results and Achievements

Head-to-Head Comparison of Scuffing Performance

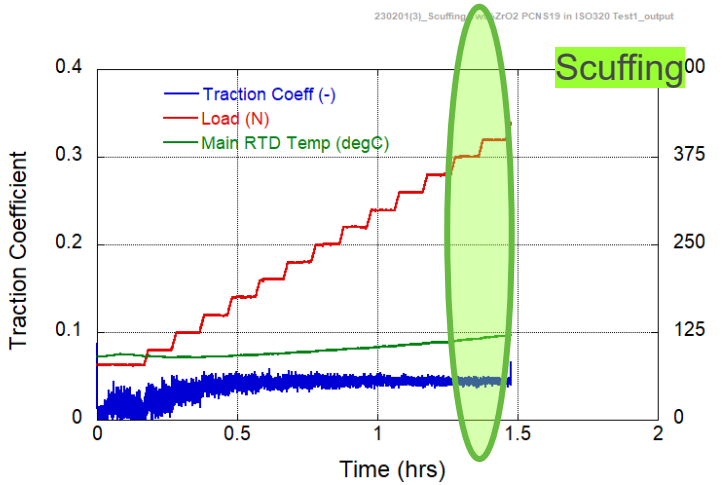
Commercial WT Lubricant (320 viscosity)



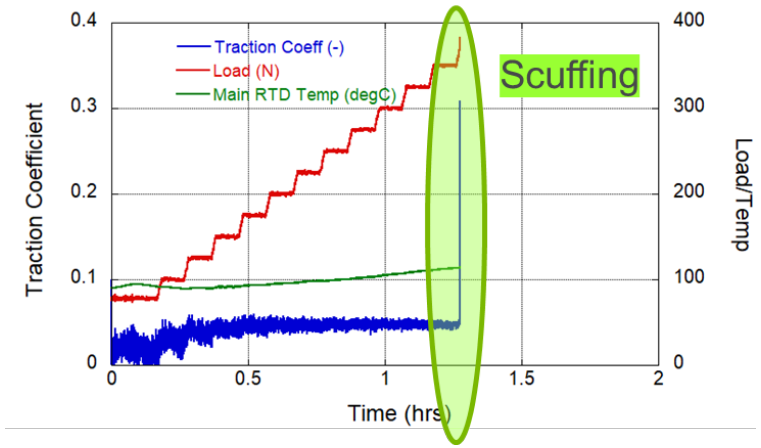
Adhesive wear due to rapid plastic deformation of surface/lack of protection/heat management

Leads to instantaneous surface failure

NFFL Lubricant (320 viscosity)



NFFL Lubricant (150 viscosity)

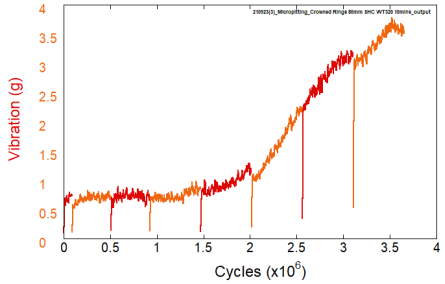


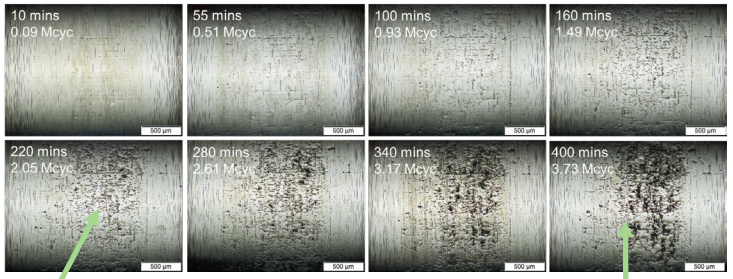
Scuffing performance by the NFFL was improved by more that 40% compared to a commercial WT lubricant, outperforming a commercial WT oil.

Results and Achievements

Head-to-Head Comparison of Micropitting Performance

Commercial WT Lubricant (320 viscosity)

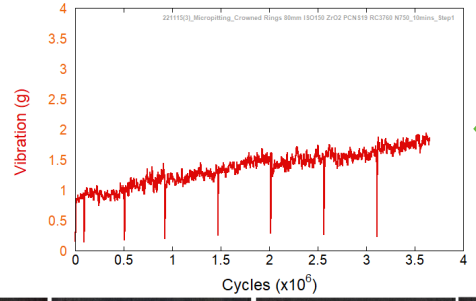




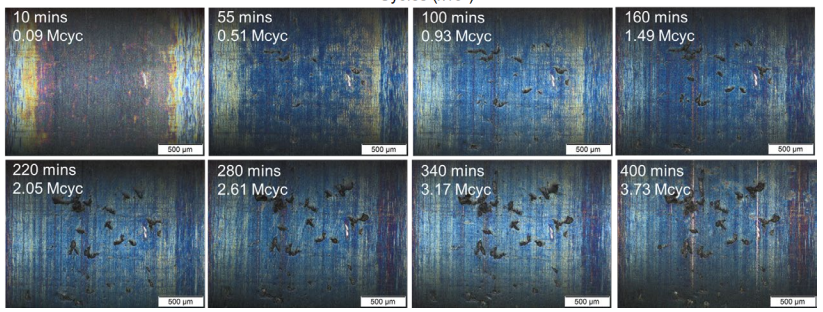
Surface pitting wear mode due to localize fatigue at surface asperities

Leads to progressive increased contact stress and macropitting failures

NFFL Formulation (150 viscosity)



Exceeded performance compared to commercial WT oil at lower viscosity

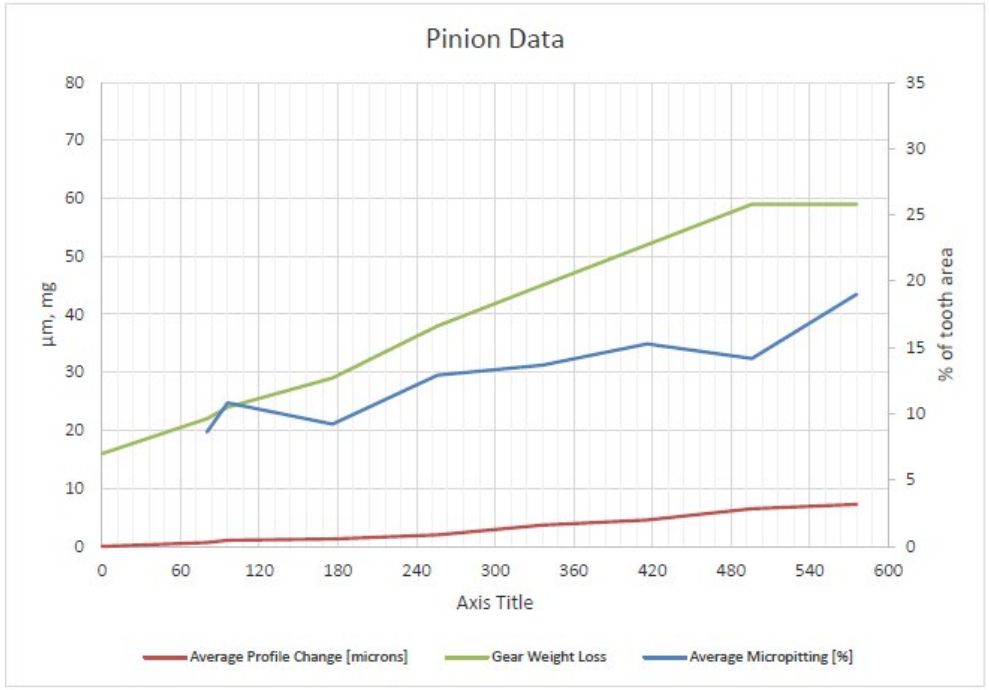


Visually less micropitting formation

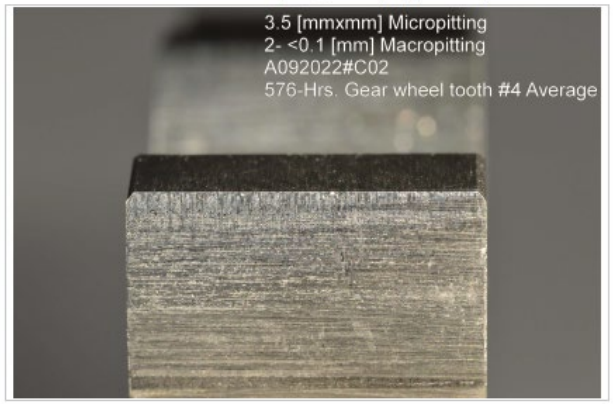
Results and Achievements

Micropitting Performance, Industrial Testing

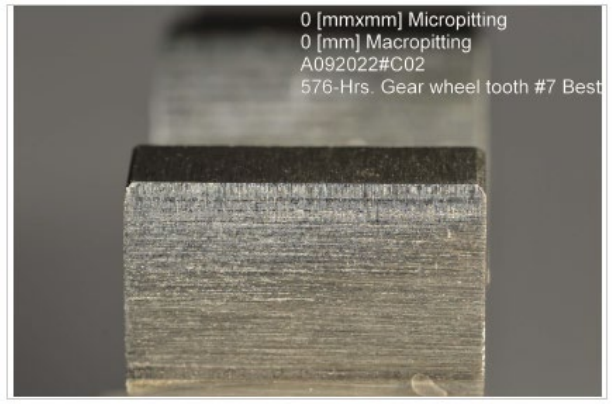
NFFL Lubricant (320 viscosity)



The objective of this industrial test is to assess the lubricating and wear protection properties of the fluid at the gear interface under set load conditions.



80 hours



580 hours

No significant change in gears

Used Standard Test Method FVA Proc No. 54

Both NFFLs showed good micropitting protection through this evaluation, successfully completing 580 of testing.

Future Work, Technology Transfer, & Impact

Future Work:

- Complete final set of industrial testing evaluation

Technology Transfer:

- We are identifying Original Equipment Manufacturers (OEMs) that use "lifetime" or "filled for life" gearboxes, with the aim of conducting potential field testing.
- We are evaluating the material as a standalone coating technology, independent of lubricants, with the goal of accelerating adoption by gear and bearing OEMs (EERE DE-EE0010211) and expediting market acceptance.

Impact:

- Upon successful completion, this project is expected to lead to cost reductions, reduced energy consumption, minimized material usage, and reduced environmental impact in the manufacturing of machine components.
- The implementation of this solution is expected to extend the service life of equipment, reduce both the manufacturing and in-service replacement costs, and increase energy efficiency during end-use
- The advantages of this technology will extend to a diverse range of industries that encounter harsh operating conditions, such as steel and aluminum rolling plants, cement mills, coal mining and processing plants, the quarrying industry, vehicles, space applications, and rotating turbine components for energy conversion.

Questions?

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