



Nanol

GREEN CHEMISTRY

Driving lubricant improvements
through innovation and science

September 2022

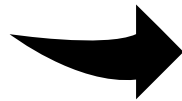
Lubricant Expo - Düsseldorf September 7th, 2022

High Performance Lubricant Innovation

WWW.NANOL.EU

Conference Theme:

Driving Improvements in the Modern Automotive Powertrain with High Performance Lubricant Innovation



- Exceed customer expectations
- Deliver OEM unmet needs
- Resolve lubrication challenges
- Improve mechanical durability
- Extend service intervals
- Raise energy efficiency
- Lower emissions
- Reduce waste disposal

Key Strategic Choices

- Strong and continued efforts within R&D
- Focus on key applications
 - Focus on reducing friction and wear in large and medium sized combustion engines
 - Materialization of the WEC mitigating/reducing effect of Nanol in bearing applications
- Co-operation with leading scientific and industrial partners



Article

Multi-Phase Friction and Wear Reduction by Copper Nanoparticles

Matthias Scherge *, Roman Böttcher, Dominik Kürten and Dominic Linsler

Fraunhofer IWM MikroTribologie Centrum, Rintheimer Querallee 2a, 76131 Karlsruhe, Germany;
roman.boettcher@iwm.fraunhofer.de (R.B.); dominik.kuerten@iwm.fraunhofer.de (D.K.);
dominic.linsler@iwm.fraunhofer.de (D.L.)

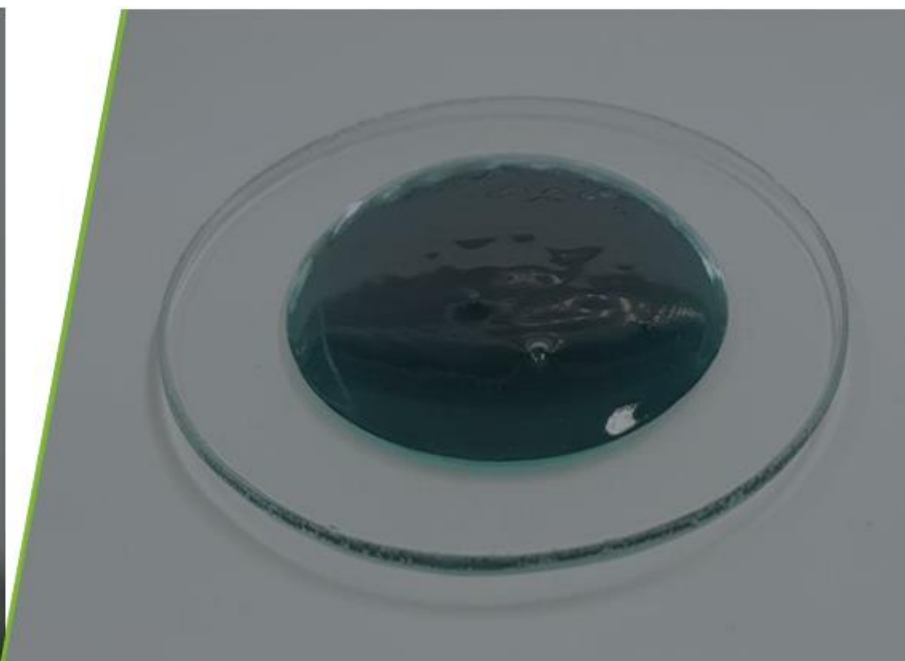
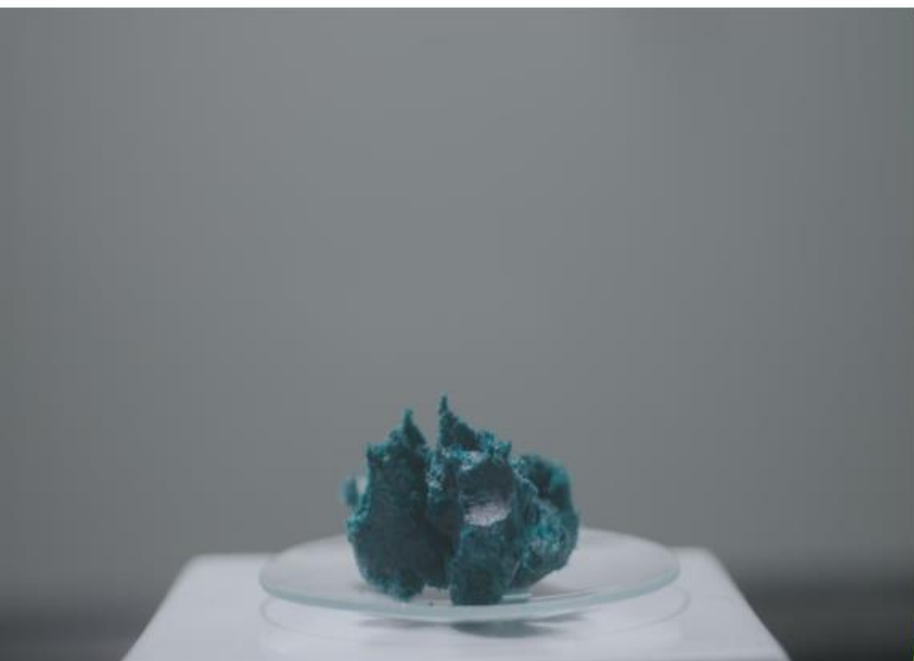
* Correspondence: matthias.scherge@iwm.fraunhofer.de; Tel.: +49-721-2043-2712

Academic Editors: Antolin Hernández Battez and Rubén González Rodríguez

Received: 19 August 2016; Accepted: 21 September 2016; Published: 18 October 2016

Abstract: Finely dispersed copper nanoparticles were added as an additive to fully-formulated engine oils. The copper additive was in colloidal form, with an inner core of Cu^{2+} atoms covered by surfactants to form stable reverse micelles that are completely dispersible in the base oil. The tribological process to form protective films at the metal surface is comprised of three phases. Phase I can be considered a physical process involving the build-up of polar molecules by absorption to produce a friction modifier film, whereas phases II and III have to be treated as mechanochemical processes comprising a combination of redox reactions and a third body formation. The tribological performance was investigated using atomic force microscopy, a microtribometer, a pin-on-disk tribometer in combination with continuous and high-resolution wear measurements with radionuclide technique, and high pressure stressing in a thrust roller bearing test rig. In addition, the nanostructure of the additive was characterized by atomic force microscopy. Finally, the chemical composition of the metal surface was analyzed using photoelectron spectroscopy.

Chemistry & Mechanism



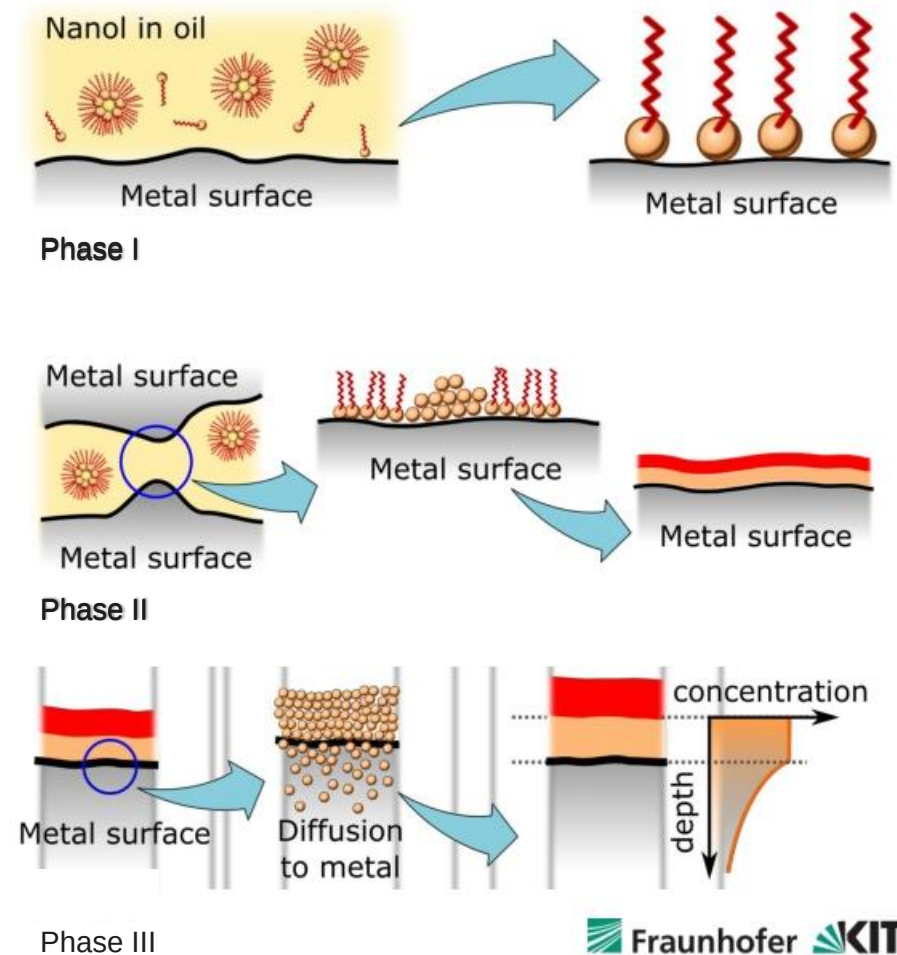
Strong Scientific Foundation

- Tribochemical & physical process occurs under boundary lubrication conditions
- Triboactivation forms thin metallic layer (tribofilm) on friction surfaces
- Continuous process ensures tribofilm consistently has optimal thickness
- Tribofilm reduces coefficient of friction and gives high load carrying capacity
- Sustained reduction in friction, protection against wear & metal fatigue, and extended service-life

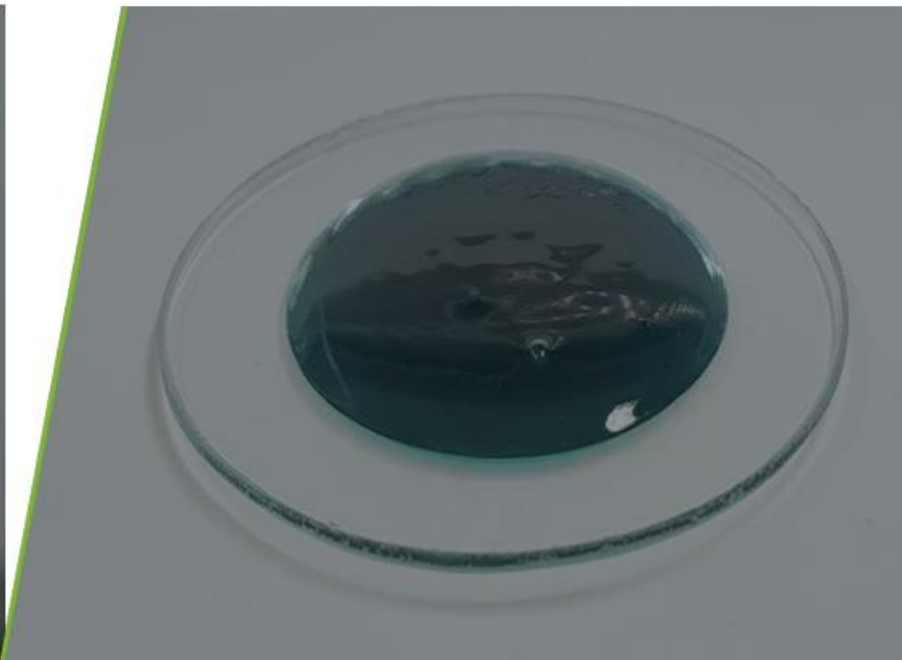
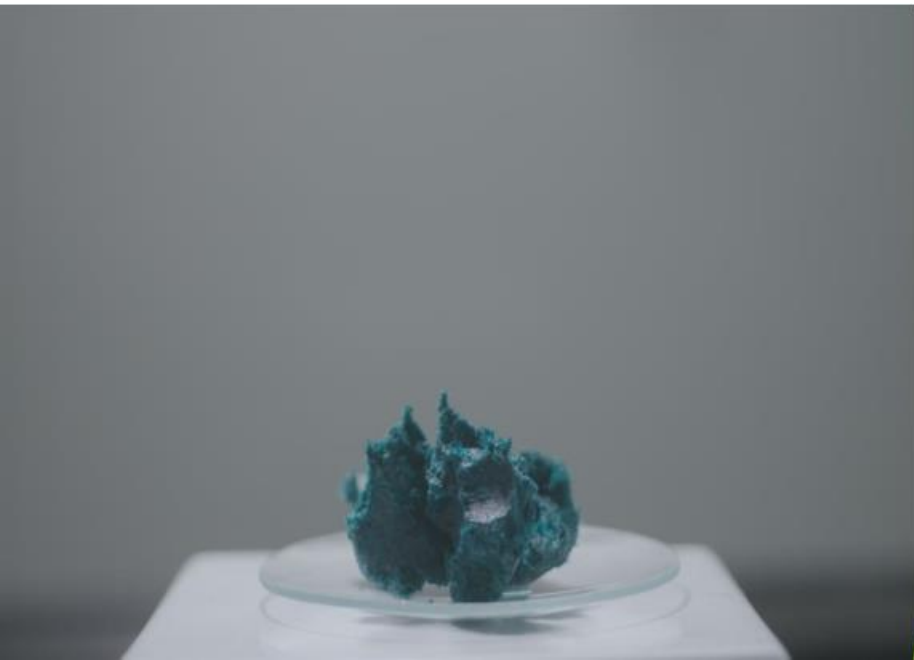


Nanol's Mechanism

- **Phase I:** Adsorption of polar head groups in copper organometallic salt to form film on friction surface
 - ⑦ Instant friction reduction
- **Phase II:** Shear-induced disruption of micelles
 - ⑦ Releases copper nanoparticles
 - ⑦ Deposit on metal surface to form tribofilm
 - ⑦ Cu^{2+} undergoes redox reaction with iron in surface
 - ⑦ Generates further Cu^0 deposits to sustain tribofilm
 - ⑦ Reinforces tribofilm
- **Phase III:** Diffusion into metal sub-surface (intermixing)
 - ⑦ Plastic flow of asperities
 - ⑦ Mechanical intermixing and tribo-chemical reactions
 - ⑦ Copper become key constituent in the third body
 - ⑦ Third body as self-regulating solid lubricant
 - ⑦ Reduces friction and improves wear protection
 - ⑦ Prevents hydrogen diffusion & metal fatigue



Performance Testing

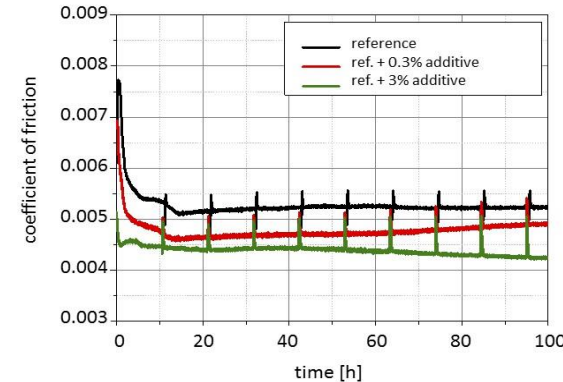


Nanol Proof & Evidence

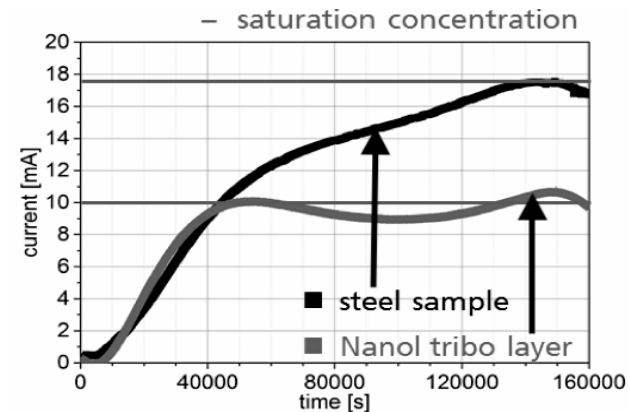
Nanol's ability to reduce friction as well as wear has been proven by a multitude of institutes, laboratories, machine producers as well as a wide range of customers.

Since the first evidences seen during the work at Fraunhofer in 2015 the product has been developed further.

Nanol's ability to mitigate/reduce WEC has been proved by Fraunhofer and several machine producers



- Microtribometer tests conducted with reference oil containing Nanol additive
- Produces an instantaneous reduction in the coefficient of friction



- Test with Nanol additive had much lower hydrogen saturation point
- Confirms Nanol reduces hydrogen diffusion
- Untreated membrane had much higher hydrogen saturation concentration
- Hydrogen permeation steel membrane tests conducted
- Nanol reduces WEC, pitting, and embrittlement

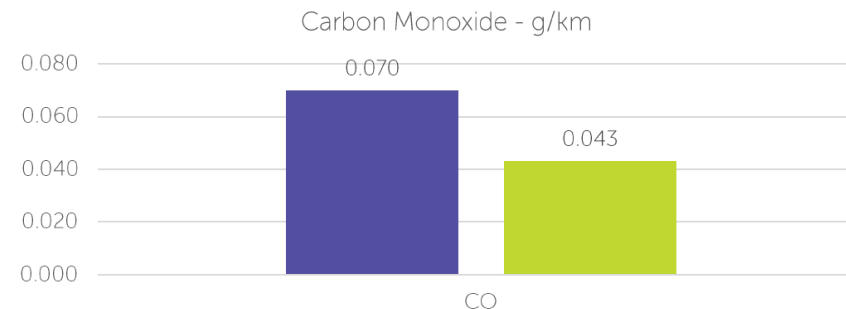
CONFIDENTIAL

Nanol Proof & Evidence

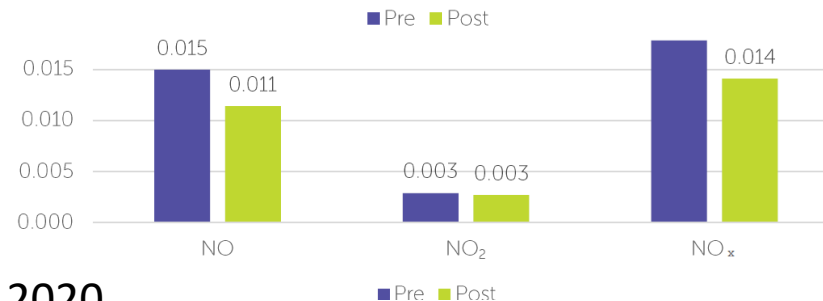
Test was successfully completed on a Skoda Scala two on 10 September 2020.

The petrol Skoda Scala recorded a statistically significant improved in fuel economy of 6% across the combined cycle after the application of the additive. Carbon monoxide decreased on the extra urban cycle by 36% and nitrogen oxides decreased by 24% over the combined cycle.

Lower CO emissions



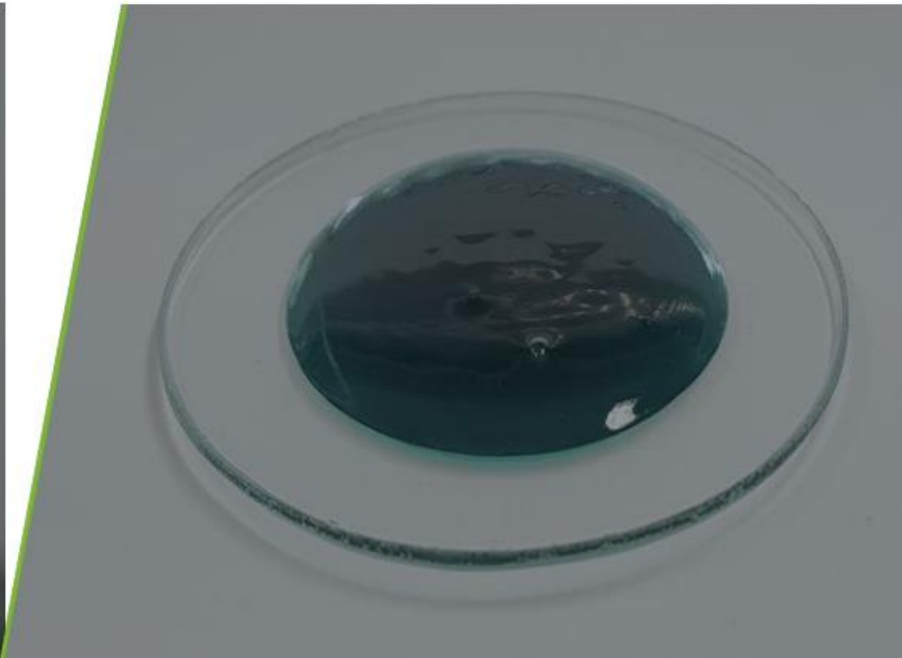
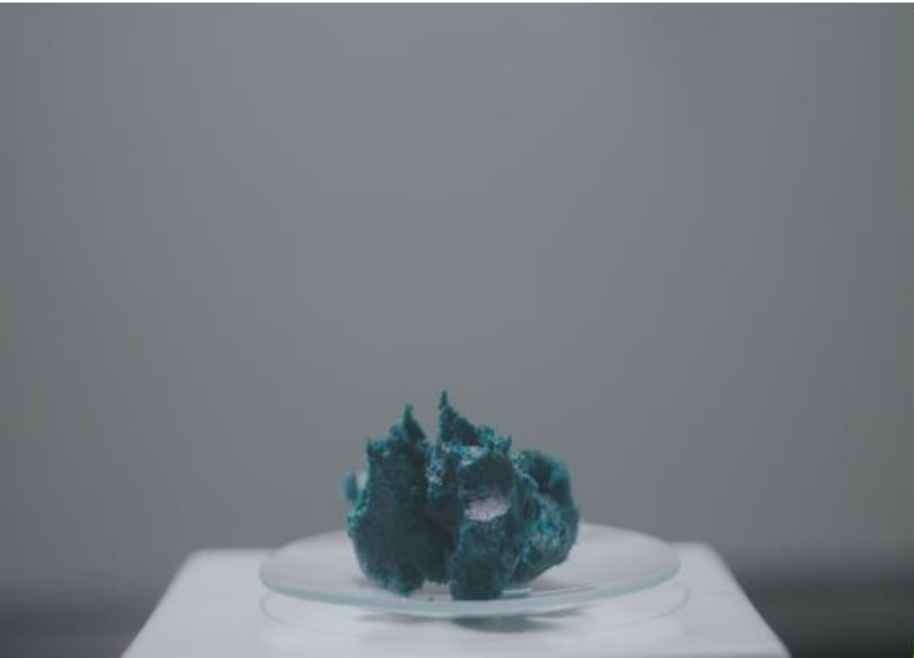
Lower NOx



Tests carried out by Emissions Analytics 2020

CONFIDENTIAL

Field Testing



Nanol Field Testing

Segment	Verified by	Key findings	Benefits and implications
Buses & cars	Swedish commercial bus fleet & private cars in Sweden & Finland	- Reduced fuel consumption - Problem-free vehicle operations	- Improved fuel economy - Reduced operating costs - Lower emissions
Bearings	Schaeffler Group & Fraunhofer Institute (Germany)	- Lifetime of bearings extended by 10x - Lower friction & significant wear reduction	- Improved mechanical durability - Extended service & maintenance cycles, less down-time - Reduced maintenance costs
Marine & Power Plant Engines	10 shipping companies > 300,000 hours of use	- Longer service intervals - Longer lifetime for lubricant oil - Reduced wear and tear	- Lower maintenance costs - Improved durability of engines - Lower hardware costs - Lower CAPEX investment
Mining	Vale, Brazil	- Re-lubrication interval extended 4.6 times - Maintenance intervals increased from 2 months up to 6.5 months - Less wear on bearings due to improved lubricity	- Less down-time - Lower lubricant costs - Increase maintenance cycles - Lower maintenance costs

Nanol's Features & Benefits

- **Multi-function additive – friction modifier, anti-wear, anti-pitting, and antioxidant**
- **Contains nanoparticles in reverse micelles, dispersed in stable oil colloid**
 - **Forms protective copper tribofilm on friction surfaces**
 - **Regenerates tribofilm to give sustained performance, doesn't deplete**
 - **Integrates into metal sub-surface to protect against metal fatigue**
 - **Reduces friction and protects against wear**
 - **Lowers oil operating temps and reduces oil oxidation & deposit formation**
 - **Reduces oil consumption, and extends oil change & service intervals**
- **No interference with function of other conventional lubricant additives**
- **Enables formulation of zero-phosphorus & low-sulphur oils**
 - **Route to improve exhaust catalyst efficiency**
- **Delivers reinvigorated technology and enables advanced performance claims**
 - **Improved wear performance with low viscosity oils and in engine stop/start systems**

Nanol's Awards

- Ranked as the “Hottest start-up in Finland”
- Nanol was selected as one of the world's most sustainable solutions by the Solar Impulse Foundation 2020
- EU funding thanks to green chemistry



Nanol Facts

- ❖ **Novel & innovative patented technology**
- ❖ **Performance independently verified by e.g., Fraunhofer Research Institute**
 - ✓ Reduces fuel consumption
 - ✓ Cuts emissions by up to 5%
 - ✓ Lowers wear rates by typically 20%
 - ✓ Prevents WEC, pitting, and metal fatigue
 - ✓ Reduces oil consumption by typically 5%
 - ✓ Extends oil change & service intervals
 - ✓ Reduces waste – cut used oil disposal
 - ✓ Lowers carbon footprint
- ❖ **Enables design of lubricants for ultra-low emission vehicles**
- ❖ **Nanol additive for oil formulations or as top-treat to lubricant**
- ❖ **Safe use - no isolated particles, REACH registered by ECHA**



Thank you!

johan.vonknorring@nanol.eu