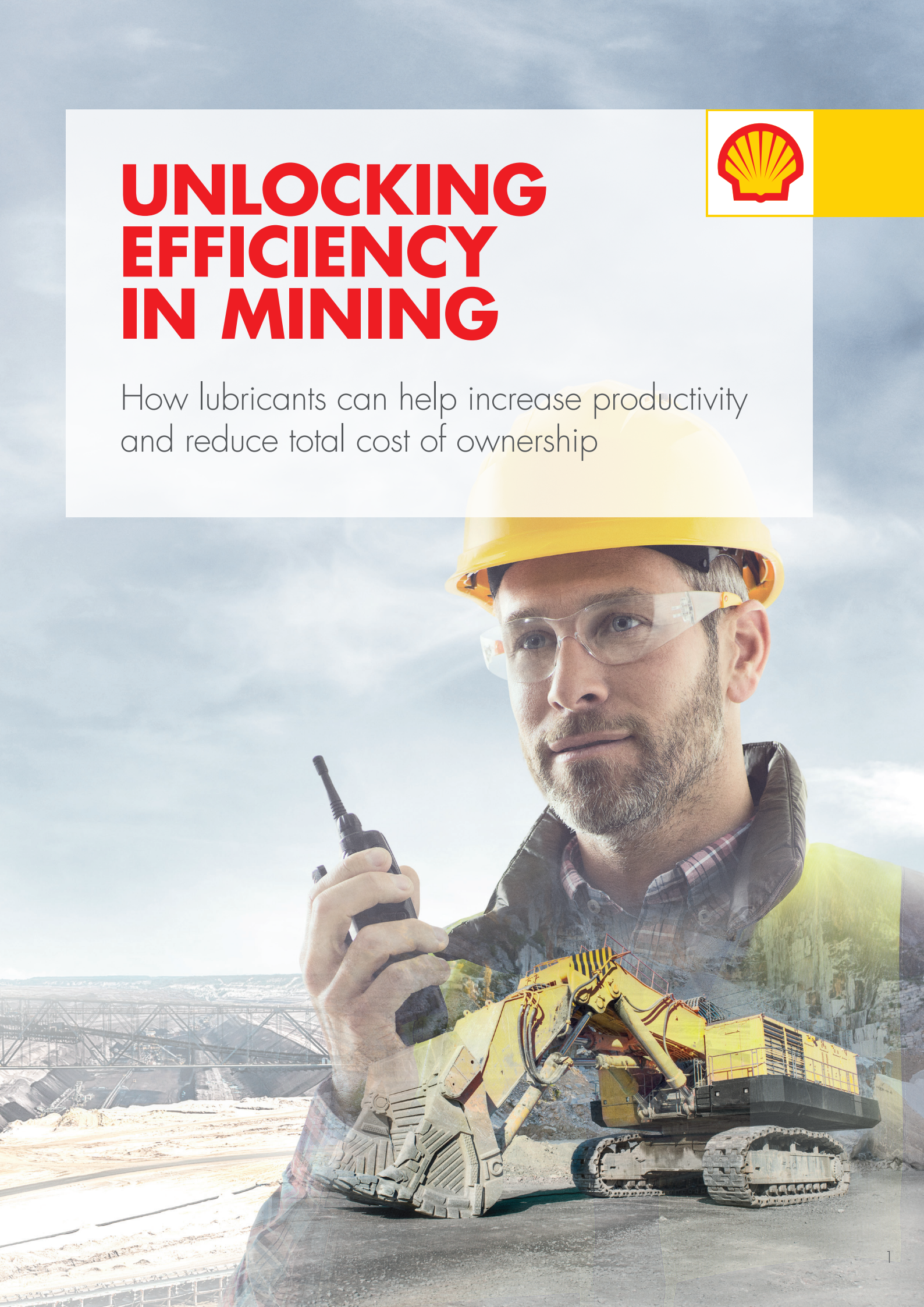
UNLOCKING EFFICIENCY IN MINING

How lubricants can help increase productivity and reduce total cost of ownership



FOREWORD

A message from Renée Power, Shell Lubricants Global Sector Manager for Mining.

After decades of working closely with customers in the mining industry, Shell Lubricants understands the challenges companies face in the current climate. Falling commodity prices, together with uncertainties about demand and oversupply makes cost competitiveness a top priority. Investment in new mines is directed to low cost, high productivity projects and existing assets are pushed to maximise production, capitalise upon economies of scale, and drive down cost per production unit.

Many mining companies already apply Total Cost of Ownership (TCO) evaluations to measure operational performance, knowing that reducing TCO over the lifetime of machinery enables them to extract the best possible value from the asset. **However, the impact of lubrication on TCO is too often underestimated.**

According to an international industry study commissioned by Shell Lubricants, 60% of companies recognise that effective lubricant selection and/or management can help reduce costs by 5% or more[1], but they undervalue the opportunity - fewer than 10% realise that the impact of lubrication could be up to six times greater[2].

Shell Lubricants believes lubrication can deliver significant business value. When considering the potential savings, the definition we use for TCO includes costs related to lost production resulting from equipment downtime[3].

In general, lubricants account for around 5% of total maintenance expenditure. Shell Lubricants technical experts have helped **mining companies achieve savings that equal their total lubricants spend,** by adopting the right approach to lubrication. They further believe that lubricants can impact up to 30% of maintenance budget. These savings are derived primarily from lower maintenance costs, reduced equipment downtime and productivity improvements.

There are two equally important elements to seizing this opportunity. The first is **selecting the right lubricant or grease**; the second is **effective lubrication management.**

In this paper, we explore the **tangible business benefits** possible from effective lubrication procedures. Case studies illustrate how mining companies around the world have successfully worked with Shell Lubricants to extract value by reducing TCO and improving productivity.

I hope you find it both informative and useful.

1. Costs include maintenance, labour, fuel.
2. This survey, commissioned by Shell Lubricants and conducted by independent research firm Edelman Intelligence, is based on 181 interviews with Mining sector staff who purchase, influence the purchase or use lubricants / greases as part of their job across 8 countries (Brazil, Canada, China, Germany, India, Russia, UK, US) from November to December 2015.
3. Total Cost of Ownership (TCO) is defined by Shell Lubricants as the total amount spent on industrial equipment, including cost of acquisition and operation over its entire working life, including costs of lost production during equipment downtime.

CONTENTS

1. TOTAL COST OF OWNERSHIP: UNDERSTANDING THE POTENTIAL

Shell Lubricants believes that there is potential for lubrication to deliver significant business value by contributing to improved productivity and reduced costs. However, the potential impact of lubricants is often significantly underestimated.

Understanding how lubricants contribute to Total Cost of Ownership (TCO) is the first step to realising potential savings.

Total Cost of Ownership (TCO)

When evaluating the effect of lubricants on TCO, Shell Lubricants considers the end to end impact on maintenance budget and processes, but also any costs related to lost production during equipment downtime. Optimising lubrication can have a significant impact on component life, maintenance costs, and unplanned downtime so can contribute to cost savings far higher than the price of the lubricant itself.

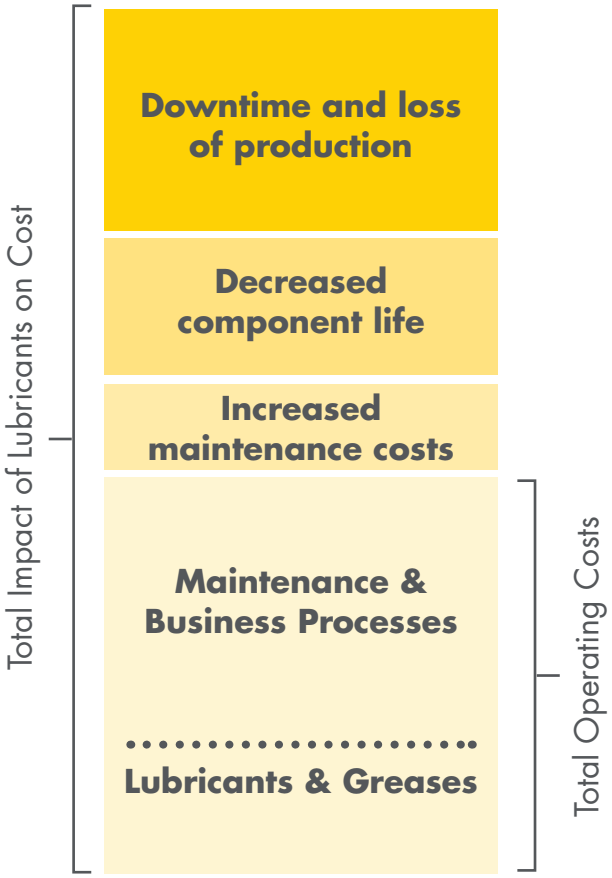
THE IMPACT OF LUBRICATION IS UNDERRATED.

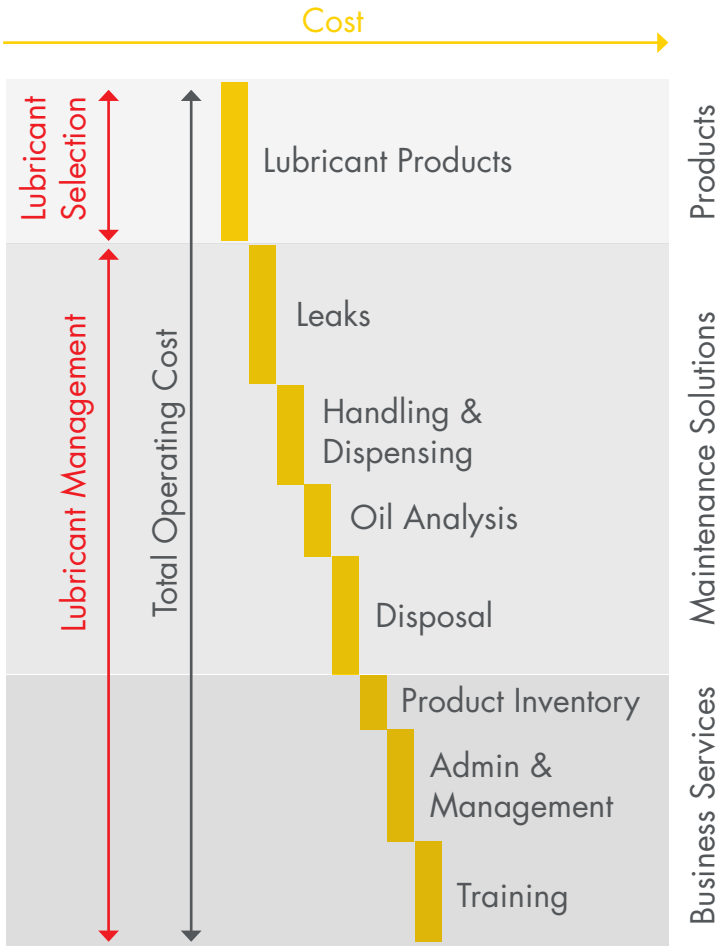
60% of companies believe they can reduce costs by >5% through lubricant selection and/or management. Only 1 in 4 think savings could exceed 10%.[2]

Seizing the Opportunity

Lubricant product selection or management can impact many elements of a company's maintenance budget. Seizing the cost-saving opportunity depends on addressing two equally important elements:

1. Selecting the right lubricant or grease - the right product
2. Effective lubrication management – including the right storage & handling, the right place, the right time, the right amount, the right monitoring and the right people





2. LUBRICANT SELECTION

Each piece of mining equipment made by different original equipment manufacturers (OEMs) has its specific lubrication requirements. OEMs define the minimum requirements for lubricants or greases, but not all products that meet these standards deliver the same level of performance.

2a. LUBRICATION CHALLENGES

Choosing the correct lubricant or grease often depends on a combination of the equipment's design characteristics, operational parameters and environment. Factors like temperature, humidity and location (altitude/underground) all pose different challenges for lubrication.

Below are three of the primary lubricant applications in the mining industry, along with some examples of specific lubrication challenges. In all cases, **selecting the right lubricant is a critical first step in improving productivity and realising significant TCO savings.**

MISCONCEPTIONS ABOUT LUBRICANTS ARE COMMON.

47% of mining companies do not believe that a higher quality lubricant/ grease can help reduce maintenance costs[2].

ENGINES

Effective engine lubrication is critical to protect high-cost equipment, and minimize downtime due to frequent oil changes, maintenance or even component failures.

Viscosity Control in Extreme Conditions:

Engine wear as a result of metal-to-metal contact can occur at low speeds, high loads, or cold starts. The lubricant helps keep moving parts separated to avoid wear. At engine start-up, particularly in cold climates, the oil must remain thin enough to circulate quickly to protect critical components. Once the engine is operating under full load, the oil needs to remain thick enough and provide the necessary protection to help prevent abrasive wear.

Soot build-up:

Accumulation of soot in the engine can lead to oil thickening and abrasive wear. This is a particular challenge in underground mines, at high altitude, and when exhaust gas recirculation (EGR) is applied as an after-treatment system.

Extended periods operating at idle load makes an engine particularly susceptible to higher rates of soot generation. The use of API CJ-4 lubricants has been found to help reduce the impact of soot accumulation. Further performance increases are expected with the implementation of API CK-4 engine oils.

Corrosion protection:

Gases and acids are generated as a natural by-product of the combustion process. The lubricant neutralises these acids to help avoid corrosion. This is particularly important in engines with Babbit-based plain bearings, which can be very susceptible to acid attack.

Long Oil Life:

Oxidation, soot accumulation and oil thickening, and the build-up of acids in the lubricant all contribute to oil aging. High quality synthetic engine oils with the right base oil and additive technology -including anti-oxidant additives -can maintain performance characteristics for longer in the presence of contaminants and by-products[4].

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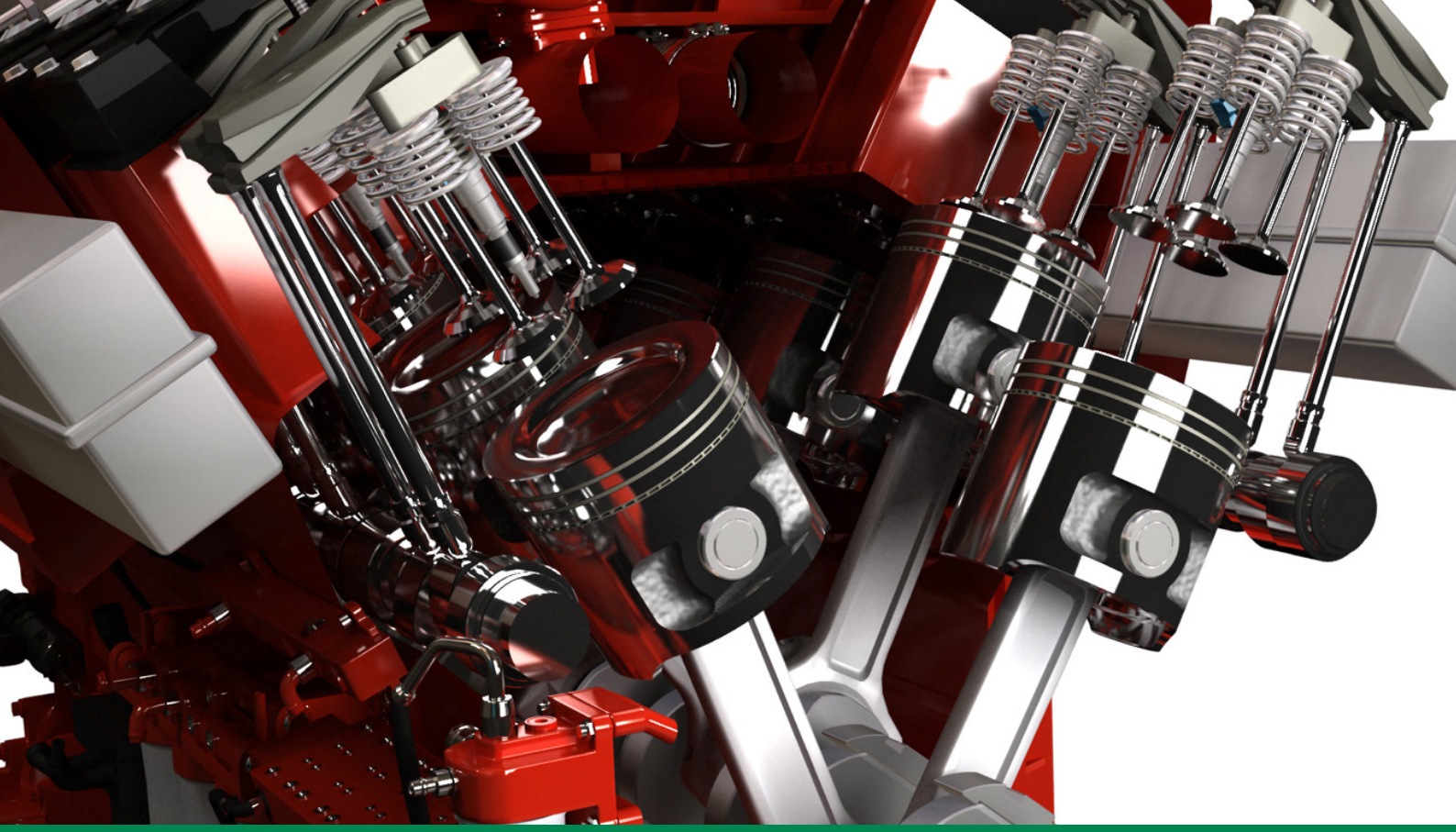
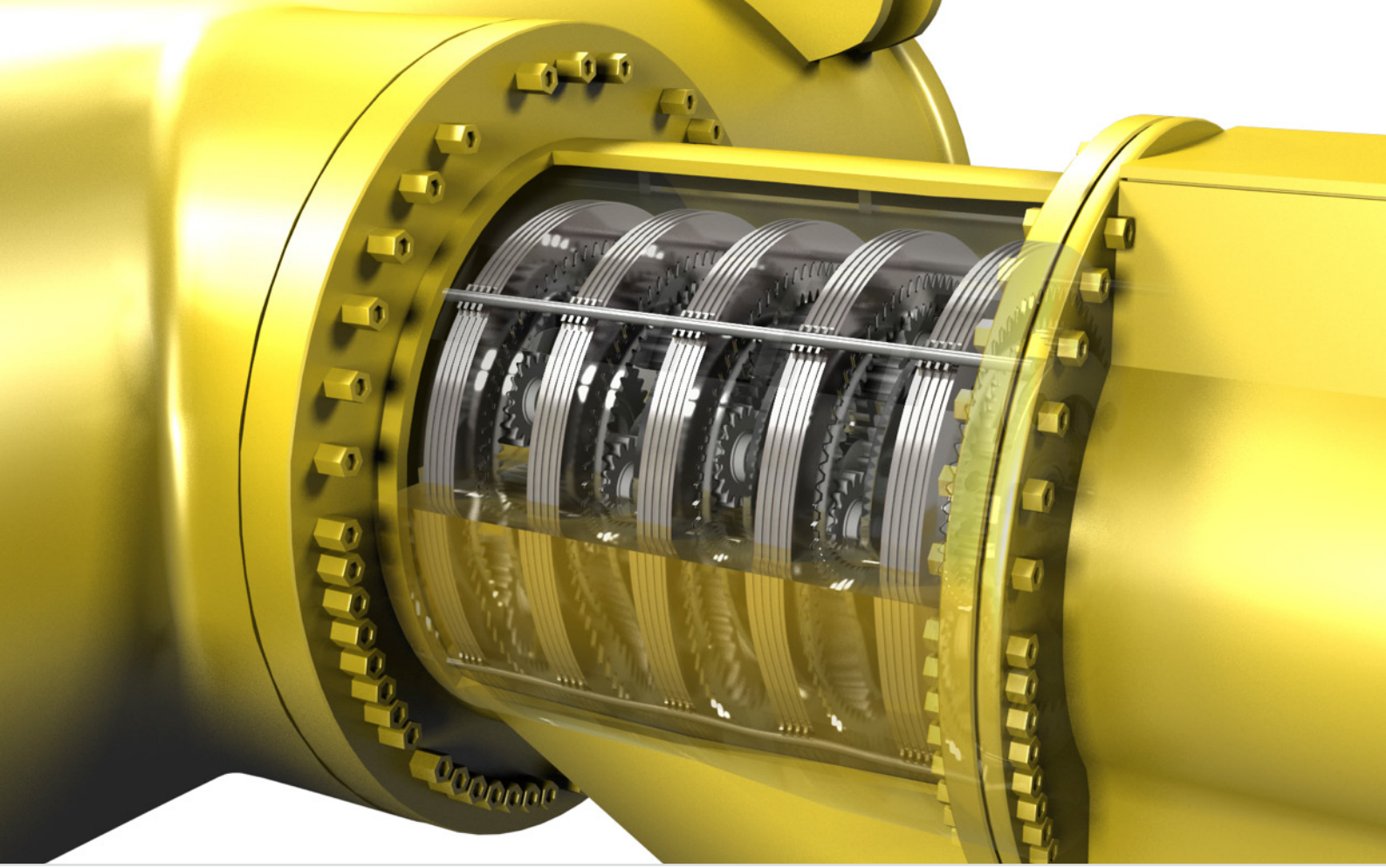
4. Compared to lower quality mineral oil alternatives.



"In today's environment, where cost reduction is key, customers rely on equipment to work harder, for longer periods. They are looking to extend equipment life, but also to spend less on maintenance. As such, there is a need to start looking beyond lubricants that just meet OEM specifications, to products that deliver increased corrosion protection, piston cleanliness and extended oil life."

– Joe Galdes, Global Mining Product Application Specialist.



DRIVELINES

Driveline technology is critical to mining operations; and component life, equipment downtime and oil drain intervals -and therefore TCO - can be significantly impacted by the quality of the oil. Equipment often operates for long periods of time at high load, which can put further stress on both the component and the oil designed to protect it.

Friction characteristics

Powershift transmissions use a series of friction plates to help engage and disengage gears. The lubricant plays a critical role in transmitting frictional force, so its frictional properties are important for effective operation. Too little friction, and the plates can slip making gear changes difficult. Too much friction, and excess heat generation can cause damage to equipment and shortened lubricant life.

Long Oil Life

Oxidation stability and corrosion protection are also important to maintain oil performance. High quality transmission and gear oils with good oxidation resistance can resist degradation and break-down over time[5], thereby reducing downtime required for frequent oil changes.

Wear Protection - Viscosity Control

In gear motors, the lubricant must help improve bearing life and give excellent protection against wear and pitting.

Transmission oil helps keep moving components apart, such as gear teeth and rolling elements, thereby avoiding metal-to-metal contact and wear. Selecting a product that has the optimal viscosity for the application, along with the required additives to protect against wear and corrosion can have a major impact on equipment life. Viscosity and shear stability are also critical for performance at a range of temperatures.

Wear Protection - Extreme pressure

In differential gears, specific contact pressures can be so high that the transmission oil is squeezed away, allowing metal-to-metal contact. The use of extreme pressure additives helps prevent the contact areas of the teeth micro-welding together.

5. Compared to lower quality mineral oil alternatives.

THE REALITY OF BETTER PRODUCT PERFORMANCE

Shell Spirax S6 CXME 5W-30 is recommended for use in heavy duty off-highway equipment. It is designed for long oil life with excellent oxidation stability[6]. It is formulated with a premium synthetic base oil, contains inhibitors to reduce oxidation and deposit formation, and is designed to protect against corrosion. All other factors remaining equal, longer oil life would extend oil drain intervals, helping reduce equipment downtime and, therefore, cost of maintenance.

Shell Spirax S6 CXME 5W-30 achieves outstanding oxidation performance in the DKA Oxidation Stability test. Dispersancy of close to 100 indicates virtually no oxidation.

"The main challenges in the transmission are generating sufficient torque force whilst protecting against component wear under extreme pressure. In mining this is vital, with equipment required to work under high loads and at steep gradients. This requires a lubricant that offers the right frictional properties and contains long-lasting anti-wear agents, anti-oxidants and extreme pressure additives."

– Greg Paluska,
Shell LubeExpert Mining Technical Services Manager – North America.

6. DKA Oxidation Stability test.

OPEN GEARS

Grease application in the mining sector can be a specialist technical area, where selecting the right grease for the right application can be critical to avoid costly equipment failures and unplanned downtime. This is particularly true for open gear applications, which are exposed to the elements in extreme conditions, and where contamination poses a significant challenge.

Wear protection in severe operating conditions

Extreme temperatures

As open gears are exposed in all climatic conditions, the grease's viscosity and pumpability is critical. In extreme cold, it must remain fluid enough to flow through grease lines to protect components, while in extreme heat it must remain thick and adhesive enough to stay on equipment surfaces.

Extreme conditions

Contamination ingress is the direct cause of about 40%[7] of open gear failure. Exposure to high levels of dust, dirt, slurry, rain and snow means open gears require greases that can maintain an adequate lubricant film and continue to flow while flushing out contamination.

Extreme pressure and shock

To help keep equipment operating at maximum efficiency, greases must be specially formulated to withstand the high load, extreme pressure, and shock-loading faced by mining machinery on a daily basis.

Application

Misapplication is the cause of around 40% of open gear failure[8]. Even a perfect lubricant cannot protect equipment if it is not applied in the right volume at the right time. Lubrication systems must be maintained and fine-tuned to ensure correct application happens.

Misalignment

Two perfectly aligned gears have a contact ratio of 100%. If misalignment causes the contact ratio to drop below 85%, the load and stress on the gearing will increase. This overloads the gears and the lubricant film and can result in sub-surface cracks and pitting, which significantly reduces component life and may result in gear failure.

7. Approximate figure based on estimate from field experience of Shell experts.
8. Approximate figure based on estimate from field experience of Shell experts.

"Exposed to the elements and working year-round in all conditions, open gears on mobile equipment are particularly susceptible to contamination. Failure of open gears can see vital machinery grind to a halt. For this type of application it's worth selecting a specialised grease, as the performance benefits in terms of equipment protection can far outweigh the investment."

– Ian Martin,
Shell Lubricants Global Grease Product Application Specialist.

2b. DELIVERING SAVINGS WITH HIGH QUALITY LUBRICANTS

Selecting a less effective lubricant rarely results in immediate equipment failure, but can lead to increased maintenance expenses over time. These mounting costs can be far greater than the savings from selecting a lower price lubricant.

In contrast, a high quality oil or grease that keeps equipment clean of deposits and effectively protects against wear and corrosion can help extend equipment life, reduce frequency of breakdowns and increase the machine's availability. This could significantly decrease spend on spare parts and maintenance.

56% of mining companies acknowledge that unplanned equipment shutdowns in the last three years have been due to their incorrect selection or management of lubricants[2].

"By selecting the best-performing lubricant or grease, mining companies can realise TCO savings that reach far beyond any savings related to the price of the lubricant itself. As such, lubricant product selection should be always based on a well-considered TCO calculation.

Mike Longbottom,
Shell LubeExpert Global Mining Manager.

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Selecting the right lubricant helps reduce TCO - Case Studies

Over the last five years, Shell Lubricants has documented projects that delivered over $139 million in customer savings – $43 million[9] of which was achieved by mining companies. These savings represent only a portion of the real-world total, which could be as much as 10 times higher. This indicates great potential for TCO reduction and productivity increases across the industry through lubrication excellence.

The following case studies demonstrate how Shell Lubricants has worked together with mining companies to support them in selecting high quality lubricants and greases to help generate substantial cost savings[10].

9: Documented customer savings from 2011 to October 2015. More information available upon request.

10: Case study savings/benefits were reported by one customer. Actual savings/benefits will vary. More details available on request.

Upgrading Oil Portfolio Lowers Cost of Lubrication saves USD $100,000 annually[10]

The challenge

The challenge: One of Russia's largest gold producers operates four mine sites located in mountainous, arctic conditions. Equipment on the site includes a fleet of 50 CAT 777F dump trucks. Due to the extreme climate conditions, the company used a range of transmission lubricants meeting Caterpillar TO-4 specification, with different viscosity grades: SAE 0W-20 when temperatures were below -25°C; SAE 10W when temperatures were between -25°C and +10°C; and SAE 30 when temperatures exceeded +10°C.

The complexity of the portfolio caused logistical issues and led to errors in product selection during scheduled oil changes. The official CAT recommendation is for gearbox overhaul every 15,000 hours, but the company's equipment only achieved 10,000 hours. Likewise, CAT recommended Oil Drain Intervals (ODIs) for the transmission are 2,000 hours but the company was achieving only 1,000 hours.

The solution

Shell Lubricants was in the final stages of developing a new synthetic transmission oil, Shell Spirax S6 CXME 5W-30, designed to operate in all climate conditions and help extend ODIs. The company agreed to trial the new product, with the aim of increasing ODIs from 1,000 to 4,000 hours and extending the lifespan of the transmission through improved wear protection. The company tested the product for 1 year in some of the world's most extreme operating conditions, with temperatures ranging from -40°C in winter to +30°C in summer.

The results

Working together with Shell Lubricants technical experts enabled the company to:

- Extend Oil Drain Intervals (ODI) from 1,000 hours to 4,000 hours. Four times longer oil life significantly reduced the number of oil changes and lubricants consumption.
- Achieve estimated savings of USD $100,000 annually from reduced spend on lubricants and lower associated maintenance cost.

***Note: The saving estimate does not include potential life extension of the transmission**

10. Case study savings/benefits were reported by one customer. Actual savings/benefits will vary. More details available on request.

High performance grease reduces component failure by 80%, saving U S$189,800 per year[10]

The challenge

A South African mining company was experiencing high wear rate to pins and bushes on its fleet of 25 Sandvik Load Haul Dumpers and 13 Sandvik Roof Bolters. Over 1 year the company had 10 pin and bush failures, and 3 drill boom failures. Shell Lubricants technical experts supported the company's maintenance staff by conducting an analysis into the root cause, which showed that daily high pressure washing was removing grease from vital components.

The solution

Shell Lubricants recommended changing to Shell Gadus S3 V460D 2 grease, which has excellent resistance to water washout[11] and shock load resistance as a result of a formulation including lithium complex thickeners and shock resistant solid additives. The product has a proven track record in performing in similar conditions in other mining operations.

The Results

- Shell Gadus S3 V460D 2 was implemented across the entire fleet of haul trucks and drill rigs and results were monitored for 2.5 years.
- The field trial confirmed that Shell Gadus S3 V460D 2 delivered improved resistance to water washout. The grease was not removed during washing, providing effective lubrication of the pins and bushes. Combined with the superior shock load protection properties, this resulted in an 80% reduction in annual number of pin and bush failures (from 10 to 2) and 67% drop in boom failures (from 3 to 1).
- The customer estimated savings of US$189,800 per year due to the reduction in parts and maintenance costs.
- Further benefits included reduction in lost production due to downtime and potential lower levels of grease consumption, but these are not included in the above savings estimate.

10. Case study savings/benefits were reported by one customer. Actual savings/benefits will vary. More details available on request.
11. Less than 10% washout after 1 hour at 79°C in the ASTM D1264 water-washout test.

3. LUBRICATION MANAGEMENT

SHELL LUBRICANTS' SIX STEPS TO GOOD LUBRICATION MANAGEMENT

1. **Right storage & handling** – the lubricant must be stored in the right conditions and handled correctly to avoid contamination and preserve its key characteristics

2. **Right place** – for the oil or grease to reach the right surface it must be properly applied to the equipment

3. **Right time** – the correct frequency of oil change or re-greasing ensures the lubricant reaches the surface at the right time. Delays can result in accelerated wear

4. **Right amount** – the correct volume of lubricant or grease applied and topped up to protect moving parts effectively

5. **Right monitoring** – regular sampling and analysis to ensure the lubricant remains fit for purpose and check for early indications of equipment wear. Inspections also ensure the consistent application of the first four steps.

6. **Right people** – the competence of those who lubricate equipment can greatly affect its positive impact, particularly when it comes to ensuring all of the above happens

Even the best product cannot perform effectively if it does not reach the right surfaces at the right time, in the right amount, without being contaminated or degraded.

Effective lubrication management is vital to unlock the potential TCO cost savings. It helps deliver value from improved productivity and reductions in lubricant consumption, maintenance and operating costs.

TRAINING AND PROCESSES FACILITATE EFFECTIVE LUBRICATION.

Only **41%** of companies have all the recommended procedures in place to manage lubricants effectively* and **59%** recognise they don't conduct staff training on lubricants as regularly as they should[2].

*Shell recommended: Delivery and storage of lubricants/greases, Oil change procedures, Oil dispensing systems, Efficiency of grease lubrication systems, Oil analysis, Training employees in lubricant selection and/or management

3a. CHALLENGES AND SOLUTIONS

The following examples highlight some of the different lubrication management challenges commonly faced by mining companies, the importance of taking action to address these, as well as the available Shell Lubricants Technical services to support.

The Challenge: Right storage and handling

Contamination control is critical to maximising the performance of the lubricant in equipment. How the oil or grease is stored, handled and transported through the site greatly impacts the likelihood of contamination. Storing drums in a sheltered place and wiping the top clean before it is opened will help limit the risk of contamination by water and particles. Applying filtration can also help ensure product cleanliness before oil enters equipment.

The Solution: Exert advice and staff training

Underpinning good lubrication management practices is industry knowledge and expertise. One of the core lubrication management services offered by Shell Lubricants is building technical competency across a customer's organisation. This is delivered through Lubricant Technical Advisors, supported by a team of Global Product Application Specialists and Lubricants Services Experts. They regularly visit mine sites to share expertise with customers about lubrication management.

The Challenge: Right Monitoring

Regular monitoring and analysis helps ensure the lubricant or grease is functioning well and remains fit for purpose. Lubricant analysis is vital to business continuity. Owners and operators of mission-critical assets need advance warning of mechanical problems that are likely to damage equipment, reduce productivity and increase maintenance costs.

Shell LubeAnalyst data show that 27% of engines, 36% of gearboxes and 30% of hydraulic systems harbor imminent or incipient failures.

The Solution: Oil Condition Monitoring Services

Oil condition monitoring services, such as Shell LubeAnalyst, can provide early warning of equipment wear or lubricant degradation, enabling the lubricant to be changed before issues escalate and thereby helping reduce the frequency, time and cost of maintenance. This also helps improve productivity due to greater equipment availability.

Certain products, such as Shell Gadus S4 OG Clear Oil, may assist in improving efficiency of monitoring for fixed plant gears on mills and large plain bearings, by allowing easy inspection without the need to shut down equipment and clean off grease. This can help reduce time, and thereby cost, of maintenance.

DID YOU KNOW?

Shell has one of the world's largest teams of technical lubricants experts for mining. This 260-strong team of Shell Lubricants technical specialists supported by distributor partners, provides a suite of lubrication management services across various industries. Their expertise usually stems from years working for a mining company or OEM. They combine a thorough understanding of mining equipment with in-depth knowledge of lubrication. This enables Shell Lubricants to help mining customers maximise equipment productivity whilst reducing TCO.

DELIVERING BUSINESS VALUE THROUGH LUBRICATION SERVICES

Shell LubeAdvisor

Identifying and Seizing Value Opportunities

Specialised Shell Lubricant Technical Advisors (LTAs) conduct site surveys to help customers identify areas for improvement in lubrication. All stages of the lubrication process are addressed, including product selection, delivery, storage, distribution across the site, product application and disposal of used lubricants. Changes are implemented and measured through 'Value Improvement Projects'.

Shell LubeExpert

Monitoring Performance

Dedicated teams of highly-trained technicians - Lubricants Service Experts (LSEs) - spend most of their time at customer sites, inspecting critical machinery like excavators, draglines, shovels, mills and kilns, and identifying potential lubrication issues. This alerts customers to the need for preventive maintenance, which can lead to savings of millions of dollars by helping to avoid major breakdowns.[12]

Shell LubeCoach

Upskilling Employees

A customised training programme, led by Shell technical experts with substantial in-field experience, which offers practical coaching to customers' staff on lubricant management techniques.

Shell LubeAnalyst

Lubricant Analysis

A global oil and equipment monitoring service that helps customers assess lubricant condition, identify potential problems, and benchmark equipment performance against comparable oil samples from around the world. Available in 95 countries and 28 languages, it has more than 60,000 users worldwide, and analyses over 750,000 samples a year. The service allows customers to monitor equipment without interrupting operations, and provides guidance on interpretation of results.

Shell LubeAnalyst Lite

Rapid On-site Analysis

Shell LubeAnalyst Lite[14] on-site analysers deliver fast, comprehensive test results for machine lubricants including engine and gearbox oils, hydraulic fluids and power steering and transmission fluids. Maintenance staff can test lubricants on-site at any remote location and get results within 15 minutes. The service can help limit downtime and lower maintenance costs by capturing early signs of abnormal wear, and helping extend oil-drain intervals.

12. The Shell LubeExpert service is not currently available in all regions.
13. Shell LubeAnalyst Sensors provide real-time alerts to prevent imminent catastrophic failures. They do not replace periodic oil condition monitoring analysis. The Shell LubeAnalyst Sensors service is not currently available in all regions.
14. Shell LubeAnalyst Lite complements the off-site, laboratory-based service offered by Shell LubeAnalyst. Shell LubeAnalyst remains the recommended analysis service when extreme precision is more important than fast results. Shell LubeAnalyst Lite is not currently available in all regions

3b. UNLOCKING VALUE

The following case studies demonstrate how Shell Lubricants technical experts have worked together with mining companies to help upgrade lubrication management processes and generate substantial cost savings[15].

Shell LubeExpert helps Shenhua Zhungeer coal mine, China reduce operation and maintenance costs by USD $113,000[15]

The challenge:

Shenhua Group Zhungeer Energy is one of China's largest coal producing companies. In the current climate, the company is under pressure to reduce operation and maintenance costs. The open pit mine site operates six BE395 shovels, which have been running for more than 10 years. Shell Lubricants technical experts worked together with the company's maintenance team to identify reducing the maintenance costs of these shovels as a key priority. Reducing grease consumption was an important element of this.

The solution:

Shell Lubricants technical experts executed a lubrication system optimisation audit on all six BE395 shovels, to examine gear tooth wear, open gear grease coverage, injector output and frequency, and overall grease consumption. This revealed a number of significant issues, including blocked injectors that resulted in insufficient lubrication of the hoist bull gear, leading to accelerated wear of the open gearing. The audit also found injectors that were by-passing or distributing more grease than OEM specifications. As a result, the customer, with support from Shell Lubricants, replaced faulty injectors and adjusted all injectors in line with LubeExpert and OEM recommendations.

The results:

Estimated total annual savings of USD $113,000:

- Optimizing the lubrication system and injectors helped reduce grease leakage by 6%, resulting in an estimated USD $40,000 per year saving in grease consumption
- Successfully prevented breakdown of Hoist Gearing, helping avoid costly repairs, purchase of replacement components and lost production during downtime. The customer estimated associated cost savings to total USD $73,000 – a conservative estimate considering replacement cost of Hoist gearing can be USD $400,000

15. Case study savings/benefits were reported by one customer. Actual savings/benefits will vary. More details available on request.

Grease optimisation for SIS, Indonesia extends life of pins and bushes by up to 9 times, saving USD $512,764 per year[15]

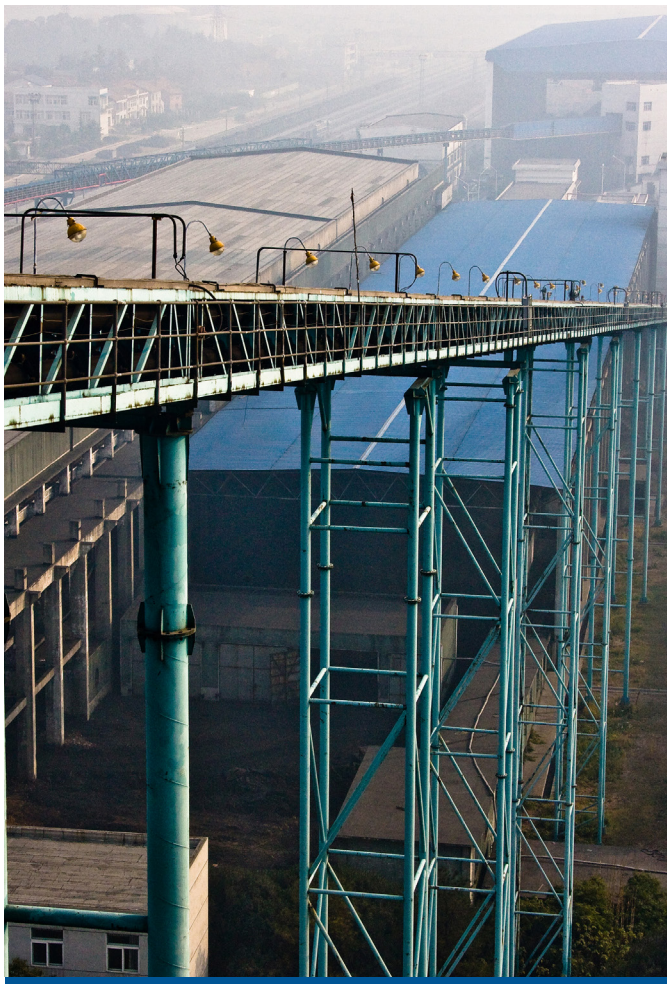
The challenge:

PT.Sapta Indra Sejati (SIS), one of the biggest mining contractors in Indonesia, was experiencing excessive wear of pins and bushes, particularly on the main bucket and pins of the Hitachi EX3600-6. Pins and bushes were lasting only 760 hours, compared to 3,000 to 4,000 hours achieved by other customers in similar conditions, leading to very high replacement costs.

The solution:

SIS was already using premium, multipurpose heavy duty grease - Shell Gadus S3 V460D 2 – a product widely recognized for its performance in the mining industry globally. However, an audit by Shell Lubricants technical experts revealed issues with its application. The grease was not reaching the pins and bushes in the right amount at the right intervals, leading to inadequate wear protection. Working together with the company's maintenance team, Shell Lubricants technical experts conducted an equipment survey, to identify the key issues and required actions:

- Injector bank position exposed grease lines to damage during operation, regularly resulting in broken grease lines. Solution: Relocate the injector bank and reroute grease lines.
- The equipment was using different types of injectors, which did not deliver the required grease volumes at the right frequency to all lubrication points. Solution: Install the appropriate injector models and adjust volumes.
- Pump pressure was not properly set up for optimum grease delivery. Solution: Set the working pressure to suit the new injectors.
- Late discovery of malfunctioning injectors or pumps. Solution: Regular excavator audits to ensure adequate greasing on an ongoing basis.



The results:

- It is estimated that SIS have saved approximately USD $730,000 since the commencement of this project with Shell Lubricants
- Customer estimated cost savings for the single Hitachi EX3600-6 excavator at USD $512,764 per year
- Life of pins and bushes on this machine extended by up to 9 times from 760 hours to over 7000 hours
- Key saving areas:
  1. Cost of spare parts: pins, bushes, seal & thrust plate
  2. Maintenance labour: to complete parts replacement
  3. Avoided production losses from equipment downtime

Shell LubeExpert helps save USD $1.2 million by preventing component failure[15]

The challenge:

South African mining company BECSA Wolvekrans was experiencing drastically shortened component life with the hoist bull gear and pinion of one of its draglines. OEM standards indicated that expected life of a pinion is four years and a bull gear eight years. Despite this, after just 18 months the hoist pinion failed when a tooth broke off. Two weeks after a new hoist pinion was fitted, inspection by Shell Lubricants technical experts revealed plastic deformation ('rippling') on the contact surface of the pinion. Rippling reduces the contact surface, leading to excessive stress on components and increasing the risk of breakdown.

The solution:

Investigation by Shell Lubricants technical experts found that the initial rippling was a result of improper running-in when both the hoist bull gear and pinion were replaced. These "ripples" were left on the bull gear when the old pinion was replaced and transferred to the new pinion while under load during operation. Shell Lubricants technical experts recommended applying a lapping compound to smoothen and grow the contact surface. This helped increase the load carrying area of the gears, reducing stress and fatigue, thus extending the life of the gear set.

The results:

- A second breakdown was successfully prevented. This helped avoid: costly repairs; purchase of replacement components; and lost production during downtime.
- The life expectancy of the pinion extended from 18 months to 4 years resulting in savings of annual maintenance costs.
- The company reported total savings of over USD $1.2 million

Inspection and Troubleshooting by Shell LubeExpert saves India's Sasan mines over USD $1.1 million [15]

The challenge:

Shell Lubricants supplies Sasan coal mines in India with all its lubricant products, plus expert lubricant management services. One routine inspection by a Shell Lubricants technical experts found a fault with a section of the lubrication system on one of the company's shovels (CAT 7495HD Shovel #4). The lower load and carry rollers on both sides of the crawler were extremely dry and the system did not appear to be pumping the required amount of grease to the rollers.

The solution:

A series of tests uncovered the root cause of the problem. Opening the return line of the pump and operating it manually showed that the grease was returning to the tank after only a couple of seconds, indicating damage to the needle and seat of the vent valve. Shell Lubricants technical experts advised changing the vent valve and installing a new pump. This resolved the issue, ensuring grease could reach the injectors and be delivered to rollers in the correct volume.

The results:

- Routine machine inspection and prompt troubleshooting action helped prevent failure of the lower frame rollers from a severe lack of lubrication.
- Cost savings from avoiding component failure and extending the life of load rollers to reduce downtime on the one shovel was **USD $1,135,550** (as estimated by customer). Of this:
    1. Savings due to avoidance of component failure — **USD $559,550**
    2. Savings due to avoidance of downtime – **USD $576,000**

4. REALISING VALUE THROUGH LUBRICATION

4a. BUILDING A STRONG FOUNDATION

A look at companies who have successfully implemented structured, TCO-driven lubrication projects together with Shell Lubricants reveals a number of initial actions that help drive success.

- Senior management support of the TCO-driven approach to lubrication, to help overcome challenges such as resourcing alongside the demands of daily operations
- Appointing a project lead and allocating appropriate time and resources to a team tasked with implementing changes
- A good relationship with the lubricant supplier, whose technical teams play a key role in identifying and delivering value
- A comprehensive analysis to identify, quantify and prioritise TCO-related projects. Importantly, aligning on how value is measured enables savings to be recorded accurately. For example:
  - What is the hourly cost of maintenance and time required for repairs?
  - What is the cost of replacement parts?
  - What is the benchmark failure frequency?
  - What is the monetary value of downtime for each piece of equipment, in terms of lost production?
- Setting measurable targets to ensure that progress can be tracked

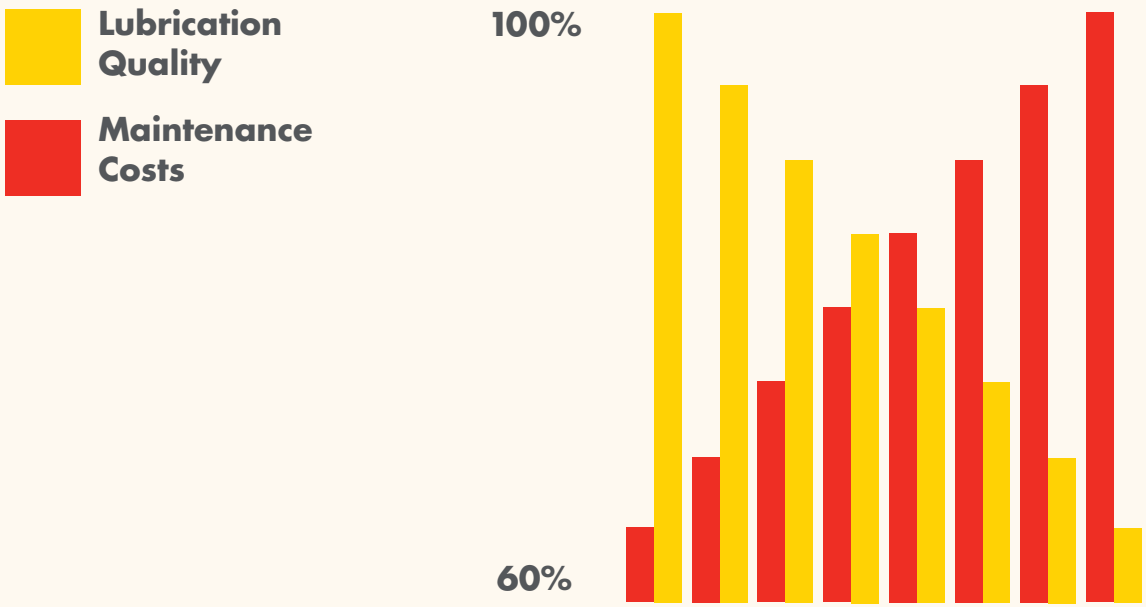
These steps will help companies form a strong foundation from which to successfully incorporate a TCO-driven approach to lubrication into daily operations, carry out lubrication improvement projects, and realise the associated cost savings.

As equipment and lubrication technology continue to evolve, regular review of the approach will help companies continue to focus effort and resources on projects that deliver greatest value.

Driving down maintenance costs

There are many factors impacting maintenance expenditure, but a direct correlation can be seen, where all other factors remaining equal, higher quality lubrication leads to lower maintenance costs.

Achieving excellence in lubrication (product selection and management) can result in far more significant reductions to total maintenance costs than purchasing lubricants based primarily on product price.



4b. A SYSTEMATIC APPROACH TO DELIVERING VALUE

Working together with customers, Shell Lubricants has developed and is now routinely using a Mine Lubrication Opportunity Survey to identify where value can be unlocked through lubrication. Shell Lubricants and the customer then collaborate to quantify, prioritise and gradually implement identified improvement opportunities.

Case studies earlier in this paper show the savings from implementing single lubrication projects. The total savings value can be significantly greater when a more systematic approach is taken, to activate multiple improvements.

SHELL LUBRICANTS HELPS ACTIVATE SYSTEMATIC APPROACH TO UPGRADING LUBRICATION.

One of the world's largest mining companies[16] worked with Shell Lubricants to activate a well-planned approach to reducing TCO by upgrading lubrication practices.

Step 1: Assessing potential

- Expenditure on lubricants accounted for 5% and lubrication management accounted for 10% of the company's annual maintenance budget.
- Using the Mine Lubrication Opportunity Survey Shell Lubricants identified that the lubrication impact represented 30% of the company's annual maintenance budget[17]
- A series of projects that could deliver value by modifying the approach to lubrication was also identified.

Step 2: Prioritising activation

- Five projects were prioritised for the first phase, identified as relatively easy to implement but with the potential to deliver high impact in cost savings, equipment availability, security and environmental footprint.
- This included improving contamination control, reducing lubricant usage through extended ODIs, and extending the life of key components such as pins and bushes or industrial bearings.
- The five priority projects were only the start of the process but represented impressive potential:
  - Potential savings totaling 4% of total annual maintenance budget (equal to 81% of total annual spend on lubricants)
  - Potential reduction of almost 1,000m3/year in amount of lubricant used, due to longer oil drain intervals (ODIs) and reduction in leakages
  - Potential reduction of 2,700 ton in CO2 emissions
  - Potential reduction of 24 ton in metallic waste
  - Potential reduction > 20,000 man hours from maintenance and accident response

Step 3: Realising value

- As an example, one of the five priority projects – extending the life of pins and bushes - delivered impressive results:
  - Savings totalling USD $1.3 million in one year
  - 51% reduction in replacement parts, helping lower costs
  - 81% fewer interventions, meaning reduced downtime
  - 46% increase in time between interventions, helping improve productivity

By continuing to follow the structured approach, the company will continue to realise cost savings over the coming years.

16. Company cannot be named for reasons of confidentiality.
17. This was in line with other mining operations in the region where savings estimates ranged from 20% to 40%.

EFFECTIVE LUBRICATION CAN HELP MINING COMPANIES LOWER TOTAL COST OF OWNERSHIP[1]

COMPANIES RECOGNISE, BUT UNDERESTIMATE, THE COST-SAVING POTENTIAL OF EFFECTIVE EQUIPMENT LUBRICATION

60%
of mining companies believe they can **reduce costs by >5%** through lubricant selection and/or management

But only
1 in 4
think savings could **exceed10%**

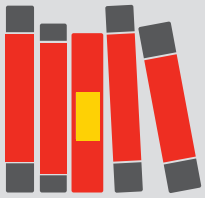
In reality lubricants can impact up to
30%
of total maintenance budget[2]

OPPORTUNITIES FOR LUBRICATION TO INCREASE PRODUCTIVITY AND LOWER COSTS ARE BEING MISSED IN THE INDUSTRY TODAY

Only
53%
believe choosing higher quality lubricants will **reduce maintenance costs**

Only
half
are clear how lubrication can influence **unplanned down time or equipment availability**

Only
4 in 10
businesses think they conduct **staff training** on lubricants as regularly as they should



Only
4 in 10
have all the **correct procedures** in place to manage lubricants effectively[3]

EFFECTIVE LUBRICANT SELECTION AND MANAGEMENT CAN HELP ENABLE COMPANIES TO ACHIEVE **TOTAL COST OF OWNERSHIP (TCO) SAVINGS** THROUGH **LOWER MAINTENANCE COSTS, REDUCED EQUIPMENT DOWNTIME, AND PRODUCTIVITY IMPROVEMENTS**

SHELL LUBRICANTS WORKS WITH CUSTOMERS TO HELP DELIVER TCO SAVINGS

At least **$43 million** savings delivered to mining companies (2011-2015)[4]

260 Shell Lubricants technical specialists help customers maximise equipment productivity and reduce TCO through lubrication

OEM and customer collaborations
enable Shell Lubricants to develop products that help improve performance, productivity and profitability

Shell Lubricants Services
to help upgrade lubrication management:

Shell LubeAdvisor
Helping identify and seize savings

Shell LubeAnalyst
Lubricant monitoring

Shell LubeExpert
Expert advice on-site

Shell LubeCoach
Staff training

This survey, commissioned by Shell Lubricants and conducted by research firm Edelman Intelligence, polled 181 decision makers in the mining industry in 8 countries (Brazil, Canada, China, Germany, India, Russia, UK, US) from November to December 2015

1. Total Cost of Ownership (TCO) is defined by Shell Lubricants as the total amount spent on industrial equipment, including cost of acquisition and operation over its entire working life, including costs of lost production during equipment downtime.
2. Potential impact calculated based on Shell Lubricants site surveys with mining customers.
3. Shell recommended lubrication management procedures include delivery and storage, oil change, oil dispensing systems, efficiency of grease lubrication systems, oil and training employees in lubricant selection or management.
4. Based on savings delivered to Shell Lubricants customers from 2011-2015

SHELL LUBRICANTS
TOGETHER ANYTHING IS POSSIBLE

5. WHAT'S NEXT?

As well as supporting customers in the present day, Shell Lubricants is always looking to identify opportunities for the next generation of products and services that will help companies overcome the challenges of the future.

Some of the trends shaping lubrication for the mining sector that Shell Lubricants is already addressing include:

Alternative fuels - Some countries are already introducing high biodiesel blends for mining engines. These include Indonesia, which will adopt 20% biodiesel in 2016.In the long term, we also expect increasing adoption of LNG fuels for mining engines.

Equipment - Mining equipment is getting bigger, so unplanned downtime will have even greater impact in the future. Equipment is also changing to become more efficient, which means higher loads and higher temperatures -working harder for longer. At the same time, oil sumps are becoming smaller, and a lower volume of lubricant must be able to perform equally effectively in increasingly demanding applications. Oil drain intervals are also becoming longer, placing even more stress on the oil formulation.

Real-time monitoring - Applying sensor technology, such as with Shell LubeAnalyst Sensors, to enable real-time analysis of lubricant and equipment performance will play an increasingly important role.

Tightening regulation - Equipment Emissions standards are increasingly stringent -for example, with the introduction of Tier IV F which include tighter emissions requirements. Lubricant regulations are also changing for modern hardware; for example, with the new API CK-4 diesel engine oil standards in North America.

Technical innovation - As technology changes, lubricants, greases and technical services designed to address key industry problems must change, too. A strong investment in innovation to develop new products for durability, protection and extended ODIs is critical.

To foresee the changes, understand the relevance for lubrication, and respond effectively requires a deep understanding of the mining industry. Shell Lubricants is always looking at how to deliver advanced lubrication solutions that add value to customers' businesses – now and in the years to come.

6. APPENDIX

6a. LUBRICANTS TECHNOLOGY – KEY FACTS

Four Functions of Lubricants and Greases

Each key function plays a different role in helping cut TCO. The aim is to achieve the best balance of the four, to maximise the impact of the lubricant or grease on TCO and equipment productivity.

1. Reduce friction
Lubricants form a fluid barrier between moving surfaces to reduce friction between them, helping maintain smooth running and limit wear.

2. Clean
Lubricants flush away contaminants, removing dirt and wear particles from vital areas for removal via filtration. Many also contain active detergents for more powerful cleaning.

3. Protect
Lubricants and greases form a protective barrier between moving surfaces, preventing metal-to-metal contact and wear. They also contain additives that neutralize harmful acids such as combustion by-products, that can impact equipment life. Enhanced protection helps limit wear and extend the life of components, helping to reduce spend on spare parts.

4. Cool
Lubricants absorb excess heat from high friction zones and transfer it away for cooling. This allows the equipment to function efficiently. (Not a critical function of greases)

LUBRICANT FORMULATION

A lubricant's precise blend of base oil and additive package helps ensure that it is able to deliver optimum performance for the longest possible time in a cost effective manner.

The process of creating a new lubricant or grease – from selecting components, to rigorously testing the formulation and conducting field trials – is highly complex and can take several years. In some cases lubricants evolve over decades, with developments in chemistry and technology innovations.

BASE OILS AND ADDITIVE PACKAGES

Base oils typically make up 75% to 95% of the finished product and influence many of its key characteristics. They are key to determining factors like viscosity and lubricity.

The additive package comprises up to 25% of a lubricant's composition and works to enhance key performance aspects of the base oil, to achieve optimum performance of the finished product.

Examples of how this is achieved include:

- Protection against wear to extend component life and help reduce maintenance costs. This is delivered through anti-wear additives that prevent metal-to-metal contact, extreme pressure agents that separate metal surfaces at high pressure and sometimes solid fill additives that protect against shock loads at low speeds.
- Operating operating, delivered through detergents and dispersants that help manage the accumulation of soot and other impurities. This helps avoid the build-up of sludge that can cause accelerated abrasive and corrosive wear that can impair equipment performance.
- Reduced cost of lubrication as a result of longer oil or grease life. This is achieved through anti-oxidants that help the oils deal with higher temperatures and loads, prevent corrosion, and guard against lubricant breakdown.

DID YOU KNOW?

For decades, Shell has led the way in advancing lubricants technology for the benefit of customers.

1933

Shell develops the four-ball load and wear test. Now a standard lubricants industry test, this assesses wear prevention in highly loaded contacts, like rolling element bearings and open gears.

1936

The first oil company to invent lithium greases. An important shift for the industry, significantly improving performance compared to previous generations of products. Lithium greases now represent >80% of all greases used worldwide.

1957

Introduces the first ever range of Atomic Power Lubricants: radiation-resistant lubricants used in the world's first full-scale nuclear power station.

1990s

First to market with a 'low SAPS' heavy duty engine oil. Lower levels of sulphated ash, phosphorous and sulphur help reduce diesel exhaust emissions by protecting after-treatment devices.

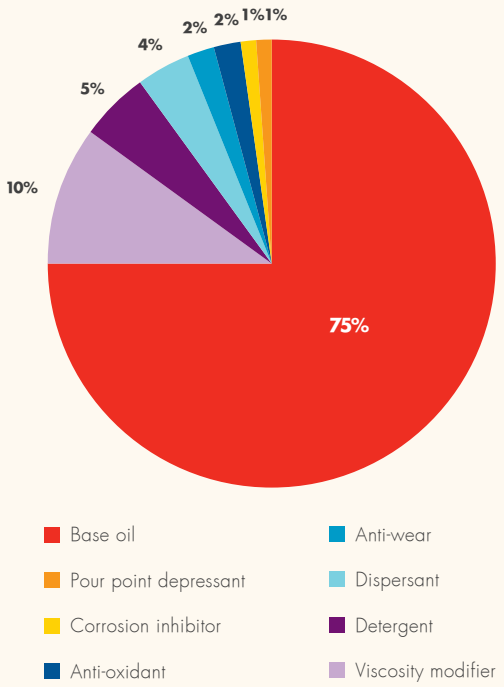
2014

First to introduce lubricants formulated from natural gas, with Shell patented gas-to-liquid technology.

2016

Shell introduces Shell LubeAnalyst Sensors, designed for real-time oil condition monitoring

Typical composition of base oil and additive package for a heavy duty diesel engine oil



GREASE THICKENERS

Greases are designed to release lubricating fluid under pressure and then reabsorb it. The life of the grease is determined by its ability to do this without changing consistency – its mechanical stability.

Base oils and additives are critical to grease formulation. In addition, grease thickener is a key component of a grease and impacts its quality. In most countries, lithium or lithium complex thickeners are used for the majority (~80%) of all applications. These deliver good water resistance, excellent mechanical stability and corrosion resistance, and remain thixotropic (fully viscous) at high temperatures. For highly specialised applications such as open gears, thickeners like bentonite or aluminium complexes may be used for their inherent temperature resistance and load carrying abilities.

PARTNERING FOR INNOVATION EXCELLENCE

Committed to delivering value to customers, Shell invests significant resources in developing new lubricants and greases for the mining industry.

A network of collaborations strengthens the innovation capabilities of Shell Lubricants Research & Development teams located in Technology Centres in Shanghai, Hamburg and Houston.

- Shell Lubricants mining portfolio has over 4,500 OEM approvals from leading manufacturers including Caterpillar, Hitachi, Komatsu, Taiyuan Heavy, and more.
- Technical Partnerships with OEMs help ensure that oils and greases are optimised for the latest equipment technology
- Field trials with customers validate performance in real-life scenarios and help steer the development of products that improve performance, productivity and profitability. For example, Shell has accumulated approximately 40 million real-world miles on API CK-4 and FA-4 prototype technologies
- Innovation is key to addressing the next generation of lubrication challenges. The Shell Lubricants Discovery Hub is a global, multi-disciplinary team focused on pushing the boundaries of current lubrication technology.