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Standard Guide for Selection of Environmentally Acceptable Lubricants for the U.S. Environmental Protection Agency (EPA) Vessel General Permit[1]

This standard is issued under the fixed designation D8324; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide provides information, without specific limits, to aid in the selection of environmentally acceptable lubricants (EALs) and use in marine applications.

1.2 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester
D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
D97 Test Method for Pour Point of Petroleum Products
D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
D217 Test Methods for Cone Penetration of Lubricating Grease
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration
D665 Test Method for Rust-Preventing Characteristics of Inhibited Mineral Oil in the Presence of Water
D892 Test Method for Foaming Characteristics of Lubricating Oils
D943 Test Method for Oxidation Characteristics of Inhibited Mineral Oils
D974 Test Method for Acid and Base Number by Color-Indicator Titration
D1264 Test Method for Determining the Water Washout Characteristics of Lubricating Greases
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D1401 Test Method for Water Separability of Petroleum Oils and Synthetic Fluids
D1742 Test Method for Oil Separation from Lubricating Grease During Storage
D1743 Test Method for Determining Corrosion Preventive Properties of Lubricating Greases
D2070 Test Method for Thermal Stability of Hydraulic Oils
D2265 Test Method for Dropping Point of Lubricating Grease Over Wide Temperature Range
D2266 Test Method for Wear Preventive Characteristics of Lubricating Grease (Four-Ball Method)
D2270 Practice for Calculating Viscosity Index from Kinematic Viscosity at 40 °C and 100 °C
D2422 Classification of Industrial Fluid Lubricants by Viscosity System
D2509 Test Method for Measurement of Load-Carrying Capacity of Lubricating Grease (Timken Method)
D2596 Test Method for Measurement of Extreme-Pressure Properties of Lubricating Grease (Four-Ball Method)
D2619 Test Method for Hydrolytic Stability of Hydraulic Fluids (Beverage Bottle Method)
D2711 Test Method for Demulsibility Characteristics of Lubricating Oils

[1] This guide is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.12 on Environmental Standards for Lubricants.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D2782 Test Method for Measurement of Extreme-Pressure Properties of Lubricating Fluids (Timken Method)
D2783 Test Method for Measurement of Extreme-Pressure Properties of Lubricating Fluids (Four-Ball Method)
D2893 Test Methods for Oxidation Characteristics of Extreme-Pressure Lubrication Oils
D3427 Test Method for Air Release Properties of Hydrocarbon Based Oils
D4048 Test Method for Detection of Copper Corrosion from Lubricating Grease
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4170 Test Method for Fretting Wear Protection by Lubricating Greases
D4172 Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four-Ball Method)
D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants
D4289 Test Method for Elastomer Compatibility of Lubricating Greases and Fluids
D4310 Test Method for Determination of Sludging and Corrosion Tendencies of Inhibited Mineral Oils
D5182 Test Method for Evaluating the Scuffing Load Capacity of Oils (FZG Visual Method)
D5483 Test Method for Oxidation Induction Time of Lubricating Greases by Pressure Differential Scanning Calorimetry
D5706 Test Method for Determining Extreme Pressure Properties of Lubricating Greases Using a High-Frequency, Linear-Oscillation (SRV) Test Machine
D5707 Test Method for Measuring Friction and Wear Properties of Lubricating Grease Using a High-Frequency, Linear-Oscillation (SRV) Test Machine
D5864 Test Method for Determining Aerobic Aquatic Biodegradation of Lubricants or Their Components
D5949 Test Method for Pour Point of Petroleum Products (Automatic Pressure Pulsing Method)
D5950 Test Method for Pour Point of Petroleum Products (Automatic Tilt Method)
D6046 Classification of Hydraulic Fluids for Environmental Impact
D6080 Practice for Defining the Viscosity Characteristics of Hydraulic Fluids
D6138 Test Method for Determination of Corrosion-Preventive Properties of Lubricating Greases Under Dynamic Wet Conditions (Emcor Test)
D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
D6425 Test Method for Measuring Friction and Wear Properties of Extreme Pressure (EP) Lubricating Oils Using SRV Test Machine
D6546 Test Methods for and Suggested Limits for Determining Compatibility of Elastomer Seals for Industrial Hydraulic Fluid Applications
D6973 Test Method for Indicating Wear Characteristics of Petroleum Hydraulic Fluids in a High Pressure Constant Volume Vane Pump
D7042 Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity)
D7043 Test Method for Indicating Wear Characteristics of Non-Petroleum and Petroleum Hydraulic Fluids in a Constant Volume Vane Pump
D7373 Test Method for Predicting Biodegradability of Lubricants Using a Bio-kinetic Model (Withdrawn 2021)[3]
D7421 Test Method for Determining Extreme Pressure Properties of Lubricating Oils Using High-Frequency, Linear-Oscillation (SRV) Test Machine
D7594 Test Method for Determining Fretting Wear Resistance of Lubricating Greases Under High Hertzian Contact Pressures Using a High-Frequency, Linear-Oscillation (SRV) Test Machine
D7752 Practice for Evaluating Compatibility of Mixtures of Hydraulic Fluids

2.2 *DIN Standards:*[4]

DIN 51350-4 Testing in the four-ball tester—Part 4: Determination of welding load of consistent lubricants
DIN 51350-5 Testing of lubricants—Testing in the four-ball tester—Part 5: Determination of wearing characteristics for consistent lubricants
DIN 51350-5E Testing in the four-ball tester—Part 5: Determination of wearing characteristics for consistent lubricants
DIN 51350-6 Shear Stability of Polymer Containing Lubricants
DIN 51354-2 Testing of lubricants; FZG gear test rig; general working principles
DIN 51389-2 Determination of lubricants; mechanical testing of hydraulic fluids in the vane cell-pump; method A for anhydrous hydraulic fluids
DIN 51517-1 Lubricants—Lubricating oils—Part 1: Lubricating oils C, Minimum requirements
DIN 51517-2 Lubricating oils—Part 3: Lubricating oils CL, Minimum requirements
DIN 51517-3 Lubricating oils—Part 3: Lubricating oils CLP, Minimum requirements
DIN 51524-3 Pressure fluids—Hydraulic oils—Part 3: HVLP hydraulic oils, Minimum requirements
DIN 51538 Testing of lubricants for refrigeration compressors for resistance to ammonia
DIN 51757 Determination of Density
DIN 51777-2 Determination of Water Content according to Karl Fischer; Indirect Method
DIN 51805 Determination of Flow Pressure of Lubricating Greases, Kesternich Method
DIN 51807-1 Determination of Water Resistance of Grease
DIN 51817-1 Determination of oil separation from greases under static conditions
DIN 51819-2 Testing of lubricants—Mechanical-dynamic testing in the roller bearing test apparatus FE8—Part 2:

[3] The last approved version of this historical standard is referenced on www.astm.org.
[4] Available from Deutsches Institut für Normung e.V. (DIN), Am DIN-Platz, Burggrafenstrasse 6, 10787 Berlin, Germany, http://www.din.de.

Test method for lubricating greases—applied test bearing: oblique ball bearing or tapered roller bearing
DIN 51819-3 Roller Bearing Test
DIN 51834 Tribological test method using a high-frequency, linear-oscillation test machine (SRV)
DIN 53505 Shore A and Shore D hardness testing of rubber

2.3 *Energy Institute Standards:*[5]
IP 121 Determination of oil separation from lubricating grease—Pressure filtration method
IP 326 Determination of extreme pressure properties of grease—Timken method
IP 530 Determination of the density of grease—Density cup method

2.4 *ISO Standards:*[6]
ISO 1817 Rubber, vulcanized or thermoplastic—Determination of the effect of liquids
ISO 2137 Determination of cone penetration of lubricating greases and petrolatum
ISO 2160 Corrosiveness to copper—Copper strip test
ISO 2176 Lubricating grease—Determination of dropping point
ISO 2592 Determination of flash and fire points—Cleveland open cup method
ISO 2909 Calculation of viscosity index from kinematic viscosity
ISO 3016 Determination of Pour Point
ISO 3104 Transparent and opaque liquids—Determination of kinematic viscosity and calculation of dynamic viscosity
ISO 3448 ISO viscosity classification
ISO 3675 Laboratory determination of density—Hydrometer method
ISO 4263-1 Petroleum and related products—Determination of the ageing behaviour of inhibited oils and fluids—TOST test—Part 1: Procedure for mineral oils
ISO 4263-3 Petroleum and related products—Determination of the ageing behaviour of inhibited oils and fluids using the TOST test—Part 3: Anhydrous procedure for synthetic hydraulic fluids
ISO 4263-4 Determination of the ageing behaviour of inhibited oils and fluids—TOST test—Part 4: Procedure for industrial gear oils
ISO 4406 Method for coding the level of contamination by solid particles
ISO 6072 Rubber—Compatibility between hydraulic fluids and standard elastomeric materials
ISO 6247 Determination of foaming characteristics of lubricating oils
ISO 6296 Determination of water—Potentiometric Karl Fischer titration method
ISO 6299 Determination of dropping point of lubricating greases (wide temperature range)
ISO 6614 Determination of water separability of petroleum oils and synthetic fluids
ISO 6618 Determination of acid or base number—Colour-indicator titration method
ISO 6619 Neutralization number—Potentiometric titration method
ISO 6743-4 Lubricants, industrial oils and related products (class L) —Classification—Part 4: Family H (Hydraulic systems)
ISO 7000-2579 Graphical symbols for use on equipment—Registered symbols
ISO 7120 Determination of rust-preventing characteristics in the presence of water
ISO/TR 7620 Rubber materials—chemical resistance
ISO 9120 Determination of air-release properties of steam turbine and other oils—Impinger method
ISO 10253 Water quality—Marine algal growth inhibition test
ISO 11007 Determination of rust-prevention characteristics of lubricating greases
ISO 11009 Determination of water washout characteristics of lubricating greases
ISO 12152 Determination of the foaming and air release properties of industrial gear oils using a spur gear test rig—Flender foam test procedure
ISO 12185 Determination of density—Oscillating U-tube method
ISO 12925-1 Lubricants, industrial oils and related products (class L)—Family C (gears)—Part 1: Specifications for lubricants for enclosed gear systems
ISO 12937 Determination of water—Coulometric Karl Fischer titration method
ISO 13357-1 Petroleum products—Determination of the filterability of lubricating oils—Part 1: Procedure for oils in the presence of water
ISO 13357-2 Determination of the filterability of lubricating oils—Part 2: Procedure for dry oils
ISO 14593 Water quality—Evaluation of ultimate aerobic biodegradability of organic compounds in aqueous medium
ISO 14635-1 FZG test method A/83/90 for relative scuffing load-carrying capacity of oils
ISO 15380 Specifications for categories HETG, HEPG, HEES and HEPR

2.5 *OECD Standards:*[7]
OECD 107 Guideline for Testing of Chemicals
OECD 117 Guideline for Testing of Chemicals
OECD 201 Guideline for Testing of Chemicals

2.6 *U.S. EPA Standards:*[8]
EPA 2013 Vessel General Permit
OCSPP Harmonized Guideline 835.3110 Criteria for Biodegradability Claims on Products Registered under FIFRA

[5] Available from Energy Institute, 61 New Cavendish St., London, W1G 7AR, U.K., http://www.energyinst.org.

[6] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

[7] Available from Organisation for Economic Cooperation and Development (OECD), 2 rue André Pascal, 75775 Paris Cedex 16, France, http://www.oecd.org.

[8] Available from United States Environmental Protection Agency (EPA), William Jefferson Clinton Bldg., 1200 Pennsylvania Ave., NW, Washington, DC 20460, http://www.epa.gov.

OCSPP Harmonized Guideline 850.1710 Oyster Bioconcentration Factor (BCF) of Test Compound

OCSPP Harmonized Guideline 850.1730 Fish Bioconcentration Factor (BCF) of Test Compound

2.7 *SIS Standards:*[9]

SS 155434 Hydraulic Fluids—Requirements and Test Methods

SS 155470 Lubricants, Industrial Oils and Similar Products—(Class L)—Specifications for Family X (Lubricating Grease)

2.8 *Other Standards:*

1907/2006 Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)[10]

CEC-L-45-A99 Viscosity Shear Stability of Transmission Lubricants[11]

DE-UZ 178 Biodegradable Lubricants and Hydraulic Fluids[12]

EN 16807 Liquid petroleum products. Bio-lubricants. Criteria and requirements of biolubricants and bio-based lubricants[13]

FVA 54/7 FZG Micro Pitting Test[14]

OSPAR Commission 2005 Protocols on Methods for the Testing of Chemicals Used in the Offshore Oil Industry[15]

3. Terminology

3.1 For definitions of terms used in this standard, refer to Terminology D4175.

3.2 *Definitions:*

3.2.1 *acute ecotoxicity, n*—the propensity of a material to produce adverse behavioral, biochemical, or physiological effects in non-human organisms or populations in a short period of time, usually not constituting a substantial portion of the life span of the organism. **D6046**

3.2.2 *biodegradation, n*—the process of chemical breakdown or transformation of a material caused by organisms or their enzymes.

3.2.3 *hydraulic fluid, n*—a liquid used in hydraulic systems for lubrication and transmission of power. **D6080**

3.2.4 *lubricating grease, n*—a semi-fluid to solid product of a dispersion of a thickener in a liquid lubricant.

3.2.4.1 *Discussion*—The dispersion of the thickener forms a two-phase system and immobilizes the liquid lubricant by surface tension and other physical forces. Other ingredients are commonly included to impart special properties. **D217**

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *accidental loss lubricant, n*—lubricant product that is used in closed systems; these products can only be released to the environment incidentally.

3.3.2 *acute ecotoxicity test, n*—protocol in which a representative subpopulation of organisms is exposed to different concentrations of a test substance for a short period (typically 24 h to 72 h), after which the impact is observed.

3.3.2.1 *Discussion*—Commonly the end-point for acute ecotoxicity testing is lethality and the concentration at which 50 % of the exposed population dies (LC50) is reported. However, sub-lethal effects may also be considered.

3.3.2.2 *Discussion*—Exposure periods substantially longer than 48 h are classified as sub-chronic studies, the exposure period must not constitute a substantial portion of the test species' life span.

3.3.3 *bioaccumulation, n*—net uptake of a material by an organism from its environment through exposure by means of water and food.

3.3.4 *bioaccumulation factor, n*—ratio of the contaminant in an organism to the concentration in the ambient environment.

3.3.5 *bioconcentration factor, n*—ratio of the concentration of a particular chemical in a living organism to the chemical's concentration in the surrounding water.

3.3.6 *gear lubricant, n*—material used to lubricate gear components.

3.3.7 *inherently biodegradable, adj*—having unequivocal evidence of biodegradability.

3.3.8 *lubricant formulation, n*—intended chemical constituents of a lubricant.

3.3.9 *partial loss lubricant, n*—lubricant that is partially released to the environment during use.

3.3.10 *polymer, n*—compound formed by the reaction of simple molecules having functional groups which permit their combination to proceed to higher molecular weights under suitable conditions.

3.3.10.1 *Discussion*—The simple molecules also known as monomers that make up a polymer can be of a single chemical configuration or many. They can be reacted to create a broad variation of polymer types including homo, random, and block polymers.

3.3.11 *readily biodegradable, adj*—arbitrary classification of chemicals which have passed certain specified screening tests for ultimate biodegradability; these tests are so stringent that it is assumed that such compounds will rapidly and completely biodegrade in aquatic environments under aerobic conditions.

3.3.12 *stern tube lubricant, n*—liquid that provides lubrication to the bearings supporting the propeller shaft within the vessel stern tube.

3.3.13 *total loss lubricant, n*—lubricant product that is fully released to the environment during use.

3.3.14 *ultimately biodegradable, adj*—having the ability to be biodegraded into carbon dioxide, biomass, water, and other inorganic substances such as ammonia.

[9] Available from Swedish Institute for Standards, Box 45443, SE-104 31, Stockholm, Sweden, sis.se/en/.

[10] Available from European Agency for Safety and Health at Work (EU-OSHA), 12 Santiago de Compostela (Edificio Miribilla), 5th Floor, E-48003 Bilbao, Spain, osha.europa.eu.

[11] Available from Coordinating European Council (CEC), Services provided by Kellen Europe, Avenue Jules Bordet 142 - 1140, Brussels, Belgium, http://www.cectests.org.

[12] Available from Blue Angel, www.blauer-engel.de/en/products/business-municipality/lubricants-hydraulic-fluids.

[13] Available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com.

[14] For referenced FVA standard, visit www.agma.org.

[15] For referenced OSPAR protocols, visit www.ospar.org.

4. Significance and Use

4.1 The purpose of this guide is to provide information on environmentally acceptable lubricants (EALs) used in marine applications. That information includes EAL types, general properties, and recommended means by which their technical performance can be evaluated. In addition, general information on the major environmental standards and other organizations and permits defining, classifying, and regulating the use of EALs are summarized.

4.2 Another goal of this guide is to provide concise tables that describe the biodegradability, ecotoxicity, and bioaccumulation requirements found in the 2013 EPA Vessel General Permit (VGP) for a lubricant to be defined as an EAL.

4.3 The scope of this guide is to provide information, without specific limits, to aid in the selection of EALs and use in marine applications. It is the intention of the preparers of the guide to provide a base knowledge of information on EALs and their use in marine applications to vessel owners and operators, vessel maintenance engineers, and preparers of marine original equipment manufacturer (OEM) lubricant requirements.

5. Classification

5.1 Users of lubricants on marine vessels would like assurance that the lubricants they use will allow their systems to operate safely with reasonable equipment life. This assurance is commonly provided by the lubricant supplier in the form of test results from specified methods indicating compliance with industry/OEM standards or demonstrated success in field use in similar systems, or both. This guide is intended to support lubricant producers and marine OEMs to develop testing protocols that demonstrate the suitability of an EAL lubricant for its intended use, and to be a reference to EAL end users to make more informed decisions on the best EAL type for their application and circumstance.

5.2 The significance and use of each test method cited in this guide will depend upon the system in use and the purpose of the test method. Use the most recent editions of ASTM International, Organization for Economic Cooperation and Development (OECD), The Coordinating European Council (CEC), International Organization for Standardization (ISO), and U.S. Environmental Protection Agency (EPA) test methods.

6. Programs and Legislation Promoting or Requiring EALs

6.1 *Ecolabel Programs Promoting EALs*—National and international labeling programs have been used to promote environmentally preferred product lubricants. These voluntary programs set specific requirements for the environmental and technical performance a product shall meet before it may use the specific ecolabel. The two most recognized national labeling programs have been DE-UZ 178 and SS 155434. The first international labeling program was the Nordic Swan program initially for greases and hydraulic, two-stroke, transmission, and gear oils. The newest of the labeling programs, the European Ecolabel program, has become the most generally accepted ecolabel internationally. In 2016, EN 16807 was approved by the European Committee for Standardization (CEN). One concept of this standard is to evaluate the environmental acceptability of a product by testing the biodegradability and ecotoxicity on the product mixture in contrast to the European Ecolabel program in which the focus is on testing of single components and not on the testing of the mixture as a whole.

6.1.1 The current criteria for a product to obtain EU Ecolabel status went into force on January 1, 2019 and will be valid until December 31, 2024. Changes from the previous iteration now in the current EU Ecolabel criteria include:

6.1.1.1 Replacement of the five application-based lubricant categories with three classifications based on the potential for loss to the environment:

(1) Total loss lubricants (TLL) that include chainsaw oils, wire rope lubricants, concrete release agents, total loss greases, and other TLL;

(2) Partial loss lubricants (PLL) that include two-stroke oils, gear oils intended for use in open gears, stern tube oils, oils for temporary protection against corrosion, and partial loss greases; and

(3) Accidental loss lubricants (ALL) that include hydraulic and metalworking fluids, closed gear oils intended for use in closed gears, and accidental loss greases;

6.1.1.2 The addition of two new lubricant types: metalworking fluids and fluids for temporary protection against corrosion;

6.1.1.3 Easing of renewable content requirements for lubricants;

6.1.1.4 Revisions in the specific requirements for excluded, limited, or restricted substances;

6.1.1.5 Revisions in the specific requirements for biodegradability; and

6.1.1.6 Addition of three criteria: Criterion 4. Origin, Traceability, and Advertising of Renewable Ingredients; Criterion 5. Packaging; and Criterion 7. Consumer Information.

6.2 *Legislation Requiring EALs*—Legislation to limit oil and lubricant leakage into the marine environment has been implemented by governments through organizations and systems including: MARPOL Annex 1, the International Maritime Organization (IMO); Marine Environment Protection Committee the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention); and the U.S. Vessel General Permit.

6.2.1 *Oslo/Paris Convention (for the Protection of the Marine Environment of the North-East Atlantic) (OSPAR)*—Adopted in 1992, OSPAR is the governing body through which 15 governments of the western coasts of Europe together with the European Union work to protect the marine environment of the northeast Atlantic. The goal of OSPAR is to prevent pollution of the marine environment through continuous reduction of emissions, discharges, and spills of hazardous substances.

6.2.2 *U.S. EPA VGP:*

6.2.2.1 On Dec. 18, 2008, the EPA VGP completed new permitting requirements for discharges incidental to the normal operation of a vessel into inland waters or the territorial sea of the United States under the National Pollutant Discharge Elimination System (NPDES). Commercial vessels subject to

TABLE 1 Summary of Lubricant Compliance Options for 2013 VGP Definition of EAL

Lubricant Compliance Options for 2013 VGP EAL Definition		Summary of Compliance Requirements
Lubricant meets requirements for EAL as defined in 2013 VGP.	Demonstrate with specific test data that the lubricant meets 2013 VGP EAL requirements.	2013 VGP EAL biodegradability, aquatic toxicity, and bioaccumulation requirements are specific for lubricants, greases, and total loss lubricants. Only test methods listed in the 2013 VGP may be used to demonstrate compliance.
Lubricant meets the requirements of environmental labeling programs listed in the 2013 VGP.	Demonstrate lubricant is registered with approved environmental program.	Requirements for Blue Angel, Nordic Swan, European Ecolabel, EPA's Design for the Environment (DfE),Swedish Standards SS 155434 and 155470
	Lubricant meets requirements of OSPAR.	Lubricant components meet the pre-screening criteria or they pose little or no risk to the environment (PLONOR) chemicals or are on REACH Annex IV or meet the criteria of REACH Annex V.

the VGP legislation were those that were greater than 24 m in length, had discharges of more than 6116 L of ballast water, had tonnage of 304 814 kg or more, or operated in California waters.

6.2.2.2 This VGP repealed a long-standing exclusion of discharges incidental to the normal operation of vessels from the NPDES program as required by the U.S. Clean Water Act. Under the Clean Water Act, all discharges of pollutants into U.S. waters are prohibited unless authorized by a duly issued permit. Authorization to discharge is obtained under Section 402 NPDES permit that authorizes the discharge of a specified amount of a pollutant or pollutants into receiving waters under certain conditions.

6.2.2.3 The 2008 VGP coverage period expired on Dec. 19, 2013 at which time the 2013 VGP coverage (EPA 2013 VGP) started and would continue for the next five-year period until Dec. 18, 2018. The 2013 VGP mandates the use of EALs for all oil-to-sea interface applications in vessels constructed on or after Dec. 19, 2013 and all vessels built before Dec. 19, 2013 unless technically infeasible. If a vessel is unable to use an EAL for a required application, the owners/operators shall document why they were unable to do so and report the use of a non-EAL product to the EPA in their annual report. The 2013 EPA VGP outlined clear requirements of biodegradability, toxicity, and bioaccumulation for a product to be defined as an environmentally acceptable lubricant (see Appendix A and B[16]). On December 4, 2018, the President signed into law the "Vessel Incidental Discharge Act" (VIDA) (Title IX of the Frank LoBiondo Coast Guard Authorization Act of 2018). VIDA restructures the way EPA and the U.S. Coast Guard (USCG) regulate incidental discharges, primarily from commercial vessels, into waters of the United States and the contiguous zone. Specifically, VIDA amends Clean Water Act (CWA) Section 312 to include a new subsection titled "Uniform National Standards for Discharges Incidental to Normal Operation of Vessels." Subsection 312(p) requires EPA to develop new national standards of performance for commercial vessel discharges and the USCG to develop corresponding implementing regulations. The existing vessel discharge requirements established through the EPA 2013 Vessel General Permit (VGP) and the USCG ballast water regulations, and any applicable state and local government requirements will apply until the EPA publishes future standards and the USCG publishes corresponding implementing regulations (see Table 1).

[16] Letter of correspondence from John V. Sherman on "Status on Development of Tables to Describe Environmental Requirements of EALs as stated in the U.S. EPA 2018 Vessel General Permit" received by Dr. In-Sik Rhee, December 6, 2017.

7. Classification of EALs

7.1 ISO has classified hydraulic fluid types including environmentally acceptable hydraulic fluids in ISO 6743-4. This standard organizes environmentally acceptable hydraulic fluids based on four base stock types from which most environmentally acceptable hydraulic fluids are derived: triglycerides (HETG), polyglycols (HEPG), synthetic esters (HEES), and polyalphaolefin and other synthetic hydrocarbons (HEPR). These same four base stocks are the basis for the manufacture of virtually all EALs developed for industrial lubricant applications, both marine and land-based. For this reason this guide will expand the use of these acronyms to represent all environmentally acceptable lubricants whose basestock is of that certain type.

7.2 *HETG Lubricants—Triglycerides (Natural Esters)*—These lubricant fluids are based on natural esters also known as triglyceride base stocks that originate from animal and plant sources. As base stocks for environmentally acceptable lubricants, natural esters are sourced exclusively from plant sources. The most common types of plant oil used for lubricant base stocks are canola (rapeseed) and soybean oil.

7.2.1 *Chemical Origin—Triglycerides (Natural Esters)*—Most plant-sourced oils are triglycerides composed of a glycerol molecule forming three ester linkages (functional groups) with various fatty acids. The diversity of properties in natural esters comes from the variation of fatty acids that can comprise the oil. The fatty acids can be of different chain lengths and number of double bonds (saturated, monounsaturated, diunsaturated, tri-unsaturated, and so forth). The physical and chemical properties of these plant oils and the hydraulic fluids made from them have been well documented and are the result of the structural differences in the fatty acid mixtures that comprise each natural oil source as well as the glycerol backbone.

7.2.2 *Compatibility with Mineral Oil, Freshwater, and Seawater—Triglycerides (Natural Esters)*—Natural esters are water insoluble and will form a separate liquid layer on top of water because of its lower density. The base oils are mainly miscible with hydrocarbon-based lubricants. Incompatibilities may result from the additive packages of specific lubricant products.

7.2.3 *Key Properties—Triglycerides (Natural Esters)*—Natural ester-based lubricants possess excellent lubricity with high-viscosity indices and flashpoints. They typically have higher pour points and less oxidative stability than EALs using other basestocks. The combination of hydrocarbon chain length, double bonds (unsaturation) present in natural esters, as well as the glycerol backbone are central reasons for these property differences from other EALs. The greater the unsaturation, the better the low-temperature properties but conversely the worse the oxidative stability. As esters, they are sensitive to hydrolysis and so are susceptible to breakdown in the presence of water and heat.

7.3 *HEPG Lubricants—Polyglycols (PAGs)*—These lubricants are based on polyalkylene glycols (PAGs), a family of synthetic polymers from petrochemical-based monomers. They are also known and referred to as PAGs, polyethers, polyols, and polyglycols. PAGs can be water soluble and oil soluble depending on the type and ratio of monomers used. The water-soluble types have the best environmental profile with respect to biodegradability, aquatic toxicity, and no bioaccumulation potential. They can be produced in a wide viscosity from 10 mm^2/s to greater than 65 000 mm^2/s in viscosity at 40 °C. For more information on the different types of oil soluble PAGs used as base stocks, as some have full and others limited oil solubility, it is recommended the PAG EAL lubricant supplier be contacted.

7.3.1 *Chemical Origin—Polyglycols (PAGs)*—Polyalkylene glycols (PAGs) are linear or branched polymers that contain oxygen (ether linkages) in their main polymer structure. They are produced by the polymerization of one or more compounds (monomers), such as ethylene oxide (EO), propylene oxide (PO), and butylene oxide (BO). The water-soluble PAG base stocks used for EAL lubricants typically comprise copolymers of EO and PO in ratios of 1:1, 3:2, and 3:1, respectively.

7.3.2 *Compatibility with Mineral Oil, Freshwater, and Seawater—Polyglycols (PAGs)*—There are different types of oil soluble PAG base stocks used to produce lubricants: some are tolerant to hydrocarbons oils and are miscible to a maximum amount of approximately 15 % by weight, while others are fully miscible in API Group I, II, III mineral oils and naphthenics. They may be fully or partially miscible with natural and synthetic esters. The water soluble PAG base stock types used for EAL applications are also fully water soluble but insoluble in hydrocarbon or ester base stocks. Incompatibilities may result from the additives packages of specific lubricant products.

7.3.3 *Key Properties—Polyglycols (PAGs)*—These lubricants are water soluble and have high-viscosity indices, low pour points, and very good lubrication. PAGs are resistant to hydrolysis. They tend to swell seals and the extent of swell increases from oil soluble to water soluble types. When PAGs decompose, the final decomposition products are soluble in the PAG base stock; therefore, all decomposition products remain in solution and do not deposit on surfaces to create sludge and residue, which may negatively impact equipment performance. PAGs are not compatible with some elastomers including types of polyurethanes and polyacrylates. PAGs are not compatible with alkyd-based paints commonly used with mineral oil lubricants but are compatible with two-part epoxy paints and coatings.

7.4 *HEES Lubricants—Synthetic Esters*—These lubricants are based on synthetic esters and defined as a class of chemical compounds containing the ester functional group. Synthetic esters can be categorized into the following classes: aromatic esters, mono-esters, di-esters, polyol esters, complex esters, and polymeric esters. The majority of synthetic esters that are EALs are of the polyol ester class including those based on trimethylolpropane, neopentyl glycol, and pentaerythritol.

7.4.1 *Chemical Origin—Synthetic Esters*—Synthetic esters are typically manufactured by reaction of carboxylic acids with an alcohol creating the ester functional group with the elimination of water molecules equivalent in number to the number of reacted acid molecules. The properties of the synthetic esters are controlled by the appropriate selection of acid and alcohol components. General ester properties depend on the number of ester groups per molecule, degree of branching, and ester molecular weight. The acid or alcohol components can be petrochemically sourced or originate from chemically modified natural esters.

7.4.2 *Compatibility with Mineral Oil, Freshwater, and Seawater—Synthetic Esters*—Synthetic ester-based lubricants are water insoluble and will form a separate liquid layer on top of water because of the lower density. They are fully soluble in mineral oil, polyalphaolefin, water insoluble, and oil soluble polyalkylene glycol-based lubricants. Incompatibilities may result from the additives packages of specific lubricant products.

7.4.3 *Key Properties—Synthetic Esters*—Synthetic ester-based lubricants demonstrate excellent thermo-oxidative stability and lubricity. Depending on their molecular size and structure, they can have very good low-temperature properties and high flashpoints. Some classes of synthetic esters are much more resistant to hydrolysis than natural esters. Lower viscosity esters have a greater tendency to swell seals and interact with paints and polymeric coatings.

7.5 *HEPR Lubricants—Polyalphaolefins and Other Synthetic Hydrocarbons*—Polyalphaolefin-based lubricants (PAOs) are produced from fully synthetic or partially synthetic partially biologically sourced saturated hydrocarbon base stocks that are very similar to mineral oil lubricants but with significantly better viscosity indices and low-temperature viscometrics. HEPR-type lubricants that are biodegradable and renewable are now available in ISO viscosity grades up to and including ISO VG 100.

7.5.1 *Chemical Origin—Polyalphaolefins and Other Synthetic Hydrocarbons*—PAOs and other synthetic hydrocarbon polymers can be produced from various monomers including alpha-olefins, internal olefins, ethylene, propylene, and isobutylene. The term "polyalphaolefins and other synthetic hydrocarbons" is not fully descriptive for the HEPR type as monomers can now be produced from bio-sourced raw materials to produce PAOs. Polyalphaolefins differ in chain length, the degree of branching, and the position of the branches. The resultant PAO synthetic base stocks are generally described by their viscosity at 100 °C.

7.5.2 *Compatibility with Mineral Oil, Freshwater, and Seawater—Polyalphaolefins and Other Synthetic Hydrocarbons*—PAO base stocks are water insoluble and will form a separate liquid layer on top of water because of their lower density. PAOs are very similar in chemical structure to paraffinic mineral oils and, therefore, are mainly miscible with these mineral oil types. Incompatibilities may result from the additives packages of specific lubricant products.