2023 STLE Trends Report – Opportunities for Tribologists!

Neil Canter

Chemical Solutions

January 9, 2024

2023 Trends Report

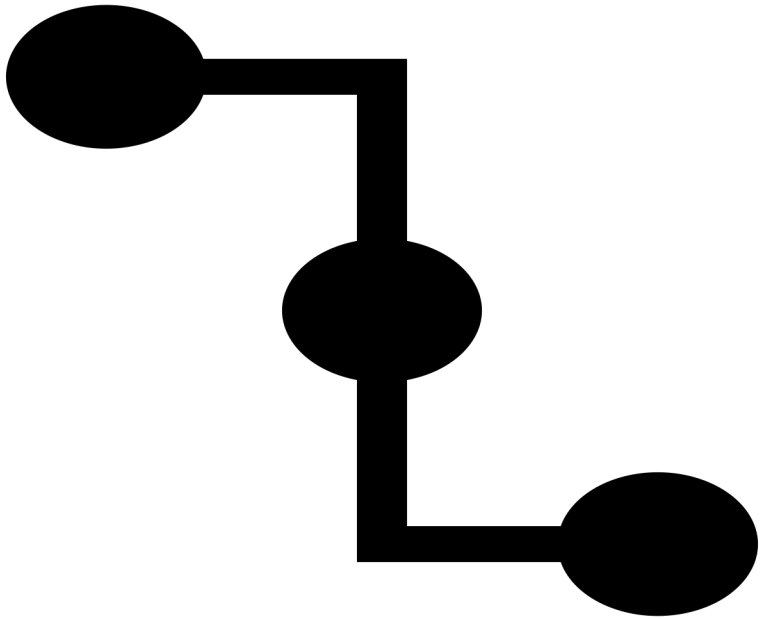
Fourth in a series of trends reports for STLE Members and those in the tribology & lubrication engineering community

Follows reports published in 2014, 2017, and 2020.

Key Trend: Quest for Sustainability!

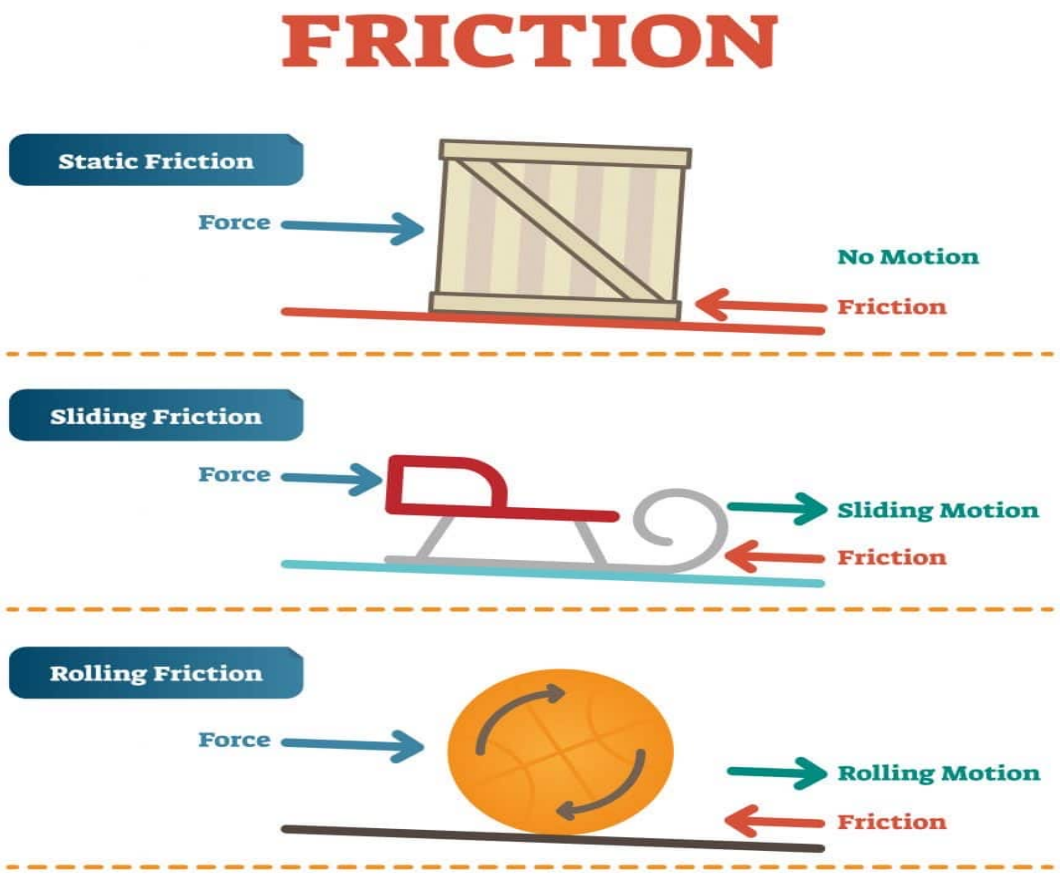
How do we as tribologists help lubricant users achieve sustainability?

Let's Connect the Dots!



What are the key functions of a lubricant?

Reduce Friction and Wear

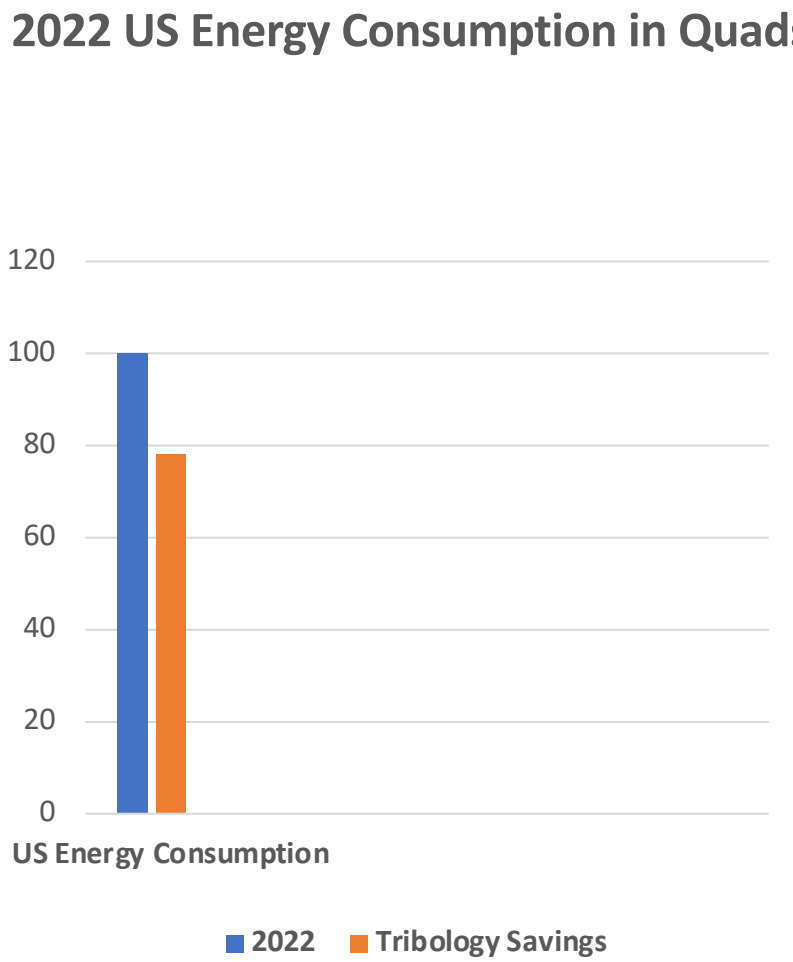


Link: https://nittygrittyscience.com/wp-content/uploads/friction-1016x1024.jpg

Results in Energy Savings!

ARPA-E 2017 Study

- "Tribology Opportunities for Enhancing America's Efficiency: A Report to the Advanced Research Projects Agency-Energy at the US Department of Energy (DOE)"
- Application of existing and novel tribology approaches can lead to over 22 quads of energy savings in the US annually
- 1 quad = 1 x 10^{15} BTU = 1.055 x 10^{18} Joules



Source US Energy Consumption is US Energy Information Agency - https://www.eia.gov/consumption/

In 2023 – To Achieve Sustainability, Need to Demonstrate Emissions Reductions!

Energy Savings → Tribology → Emissions ↓

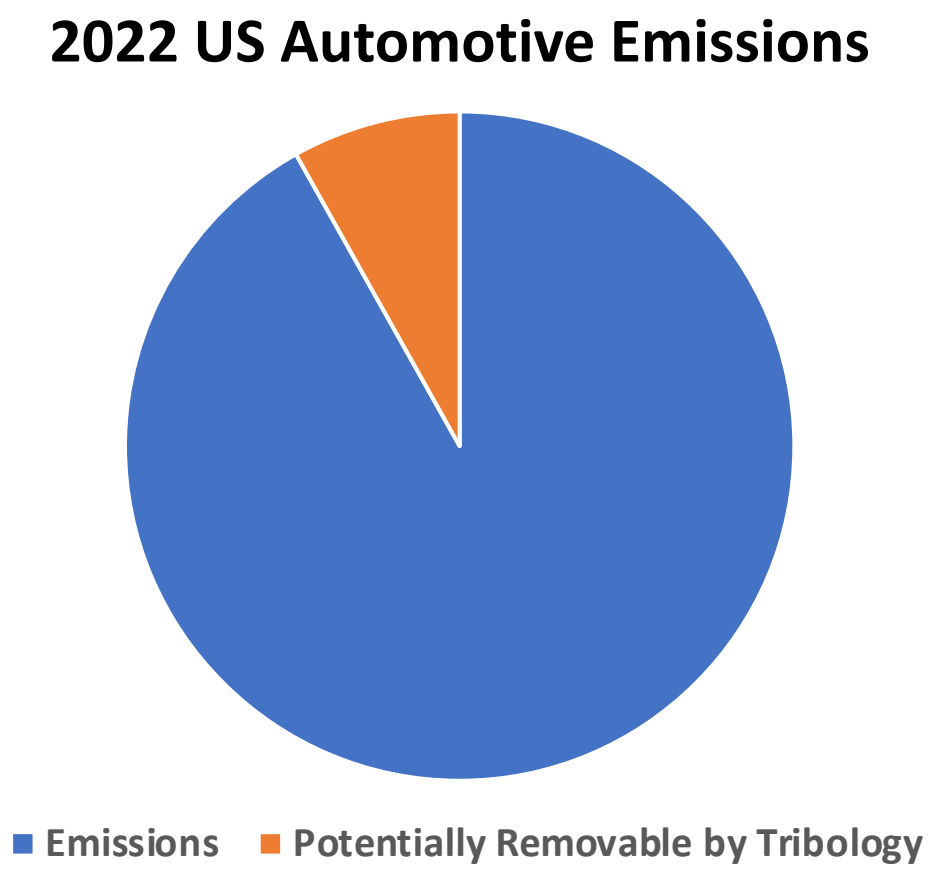
Significant Tribology Opportunity!

How Significant is the Emissions Reduction?

- 22 Quads of Energy Saved in the US
  - Eliminates 110 million metric tons of CO_2 produced in the US annually
  - Represents 5% of the US share for limiting global warming to an increase of 1.5 C by 2030

- Tribology's contribution is more significant than many other approaches for emissions reduction

What Does This Mean from an Automotive Emissions Standpoint?



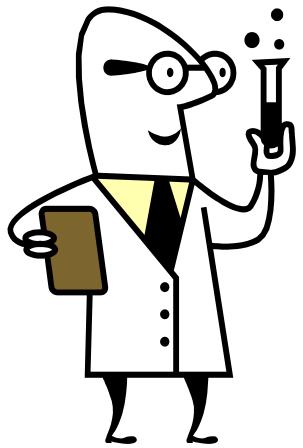
- US Bureau of Transportation – 270 Million Vehicles on the Road in the US in 2022 https://www.bts.gov/content/number-us-aircraft-vehicles-vessels-and-other-conveyances
- EPA – 4.6 metric tons emitted per year on average by 1 passenger car vehicle https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle
- Annual total passenger car emissions – 1.24 billion metric tons
- Proper tribology practices may potentially remove emissions representing 10% of US passenger cars

Key Conclusion/Opportunity:

Proper Tribology Practices →

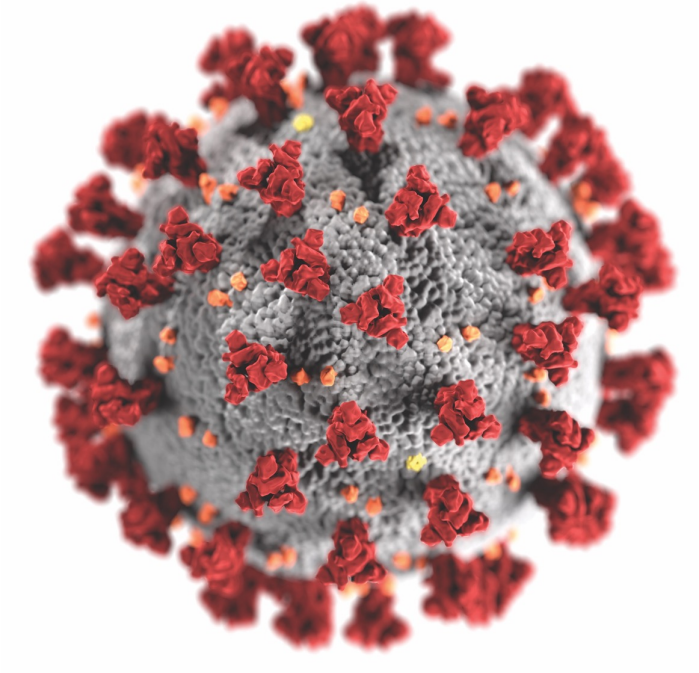
Potential to Reduce Greenhouse Gas Emissions

Play Major Role in Implementing Sustainability & Achieving Climate Change Mitigation Goals



Topics Covered in Trends Report

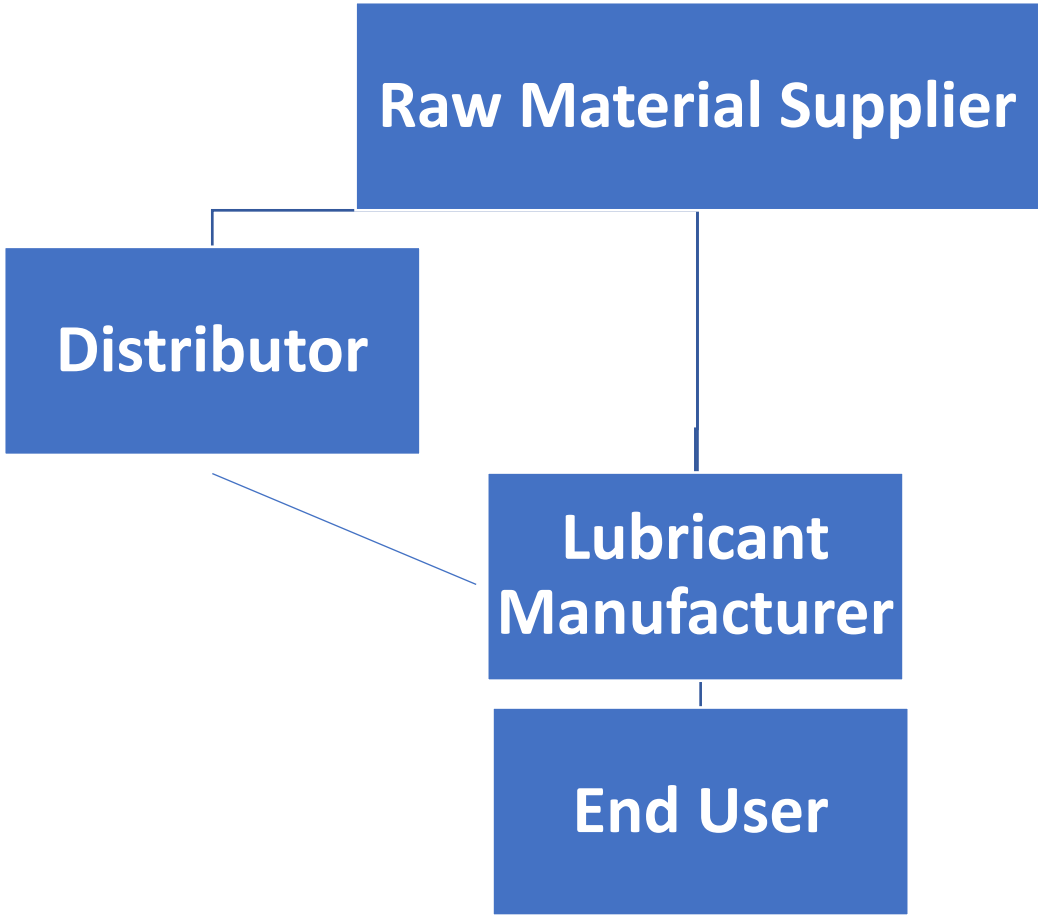
Supply Chain – Remember 2020?



COVID-1

Availability?

Supply Chain



Imagine dealing with thousands of these supply chains!

Supply Chain Risk Assessment Criteria – Identify Threats to Supply

Economics

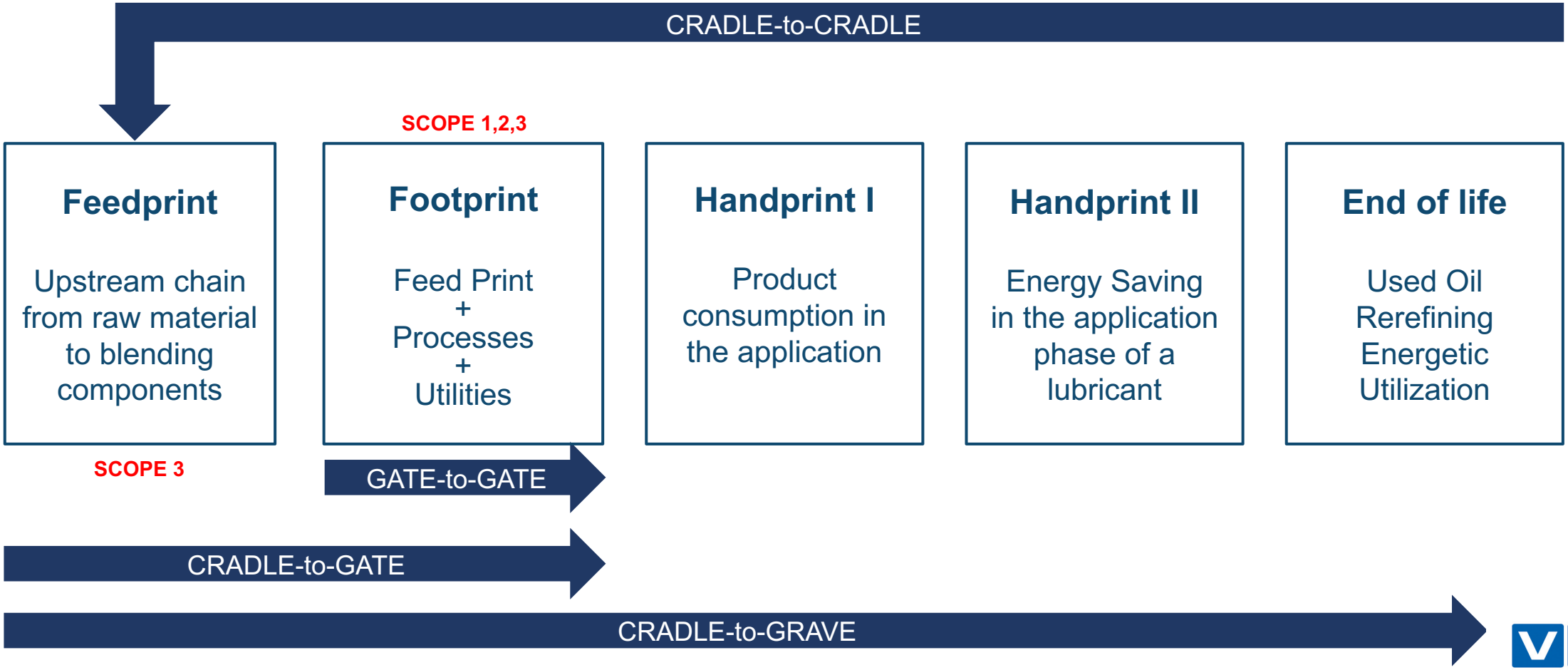
The Environment

Political and policy changes

Social structure

Social accessibility

SUPPLY CHAIN AND SUSTAINABILITY: CARBON FOOTPRINTING IN THE LUBRICANT INDUSTRY



vsi-schmierstoffe.de

How to determine the emissions produced by one lubricant over its entire life cycle?

Answer: LCA – Life Cycle Analysis

Calculation and summing of emissions produced by a product by calculating Scope 1, Scope 2 and Scope 3 emissions.

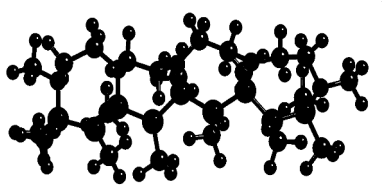
What to do?

Identify and quantify environmental loads found in a process, including energy and raw materials consumed, emissions and waste generated.

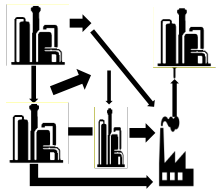
Analyze the potential environmental impacts of these loads.

Determine what options are available to reduce the environmental impacts identified.

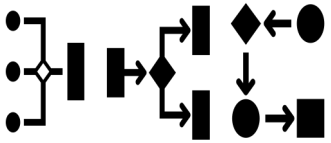
One challenge: How to deal with additives?



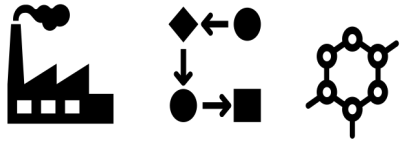
complex chemistry



complex value chain



diverse process chain



different processes
same molecule

Intellectual property

vsi-schmierstoffe.de

As a Reminder: Key Metalworking Fluid Additives (In Alphabetical Order)

Biocides
Antimist Agents (Usually tankside addition)
Antioxidants (mainly in straight oils)
Boundary Lubricity Additives
Coupling Agents
Corrosion Inhibitors
Defoamers
Dyes
Emulsifiers
Extreme Pressure Agents
Metal Deactivators
Reserve Alkalinity Boosters (Amines)
Wetting Agents

One Additional Problem

No agreed to definition of sustainability??

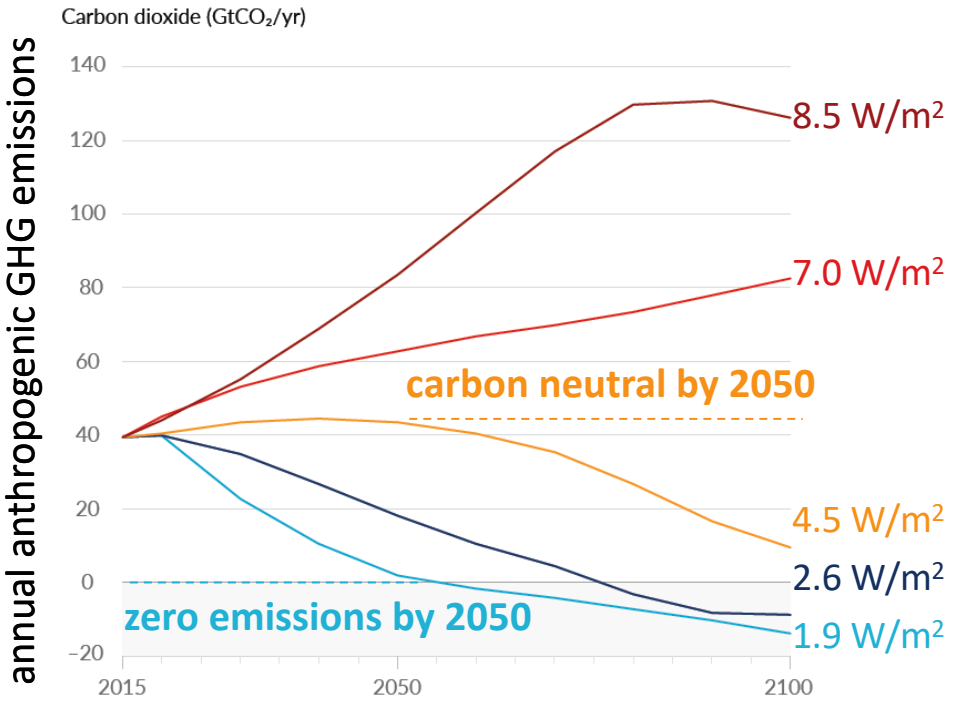
Only guideline is United Nation's (UN) 1987 definition

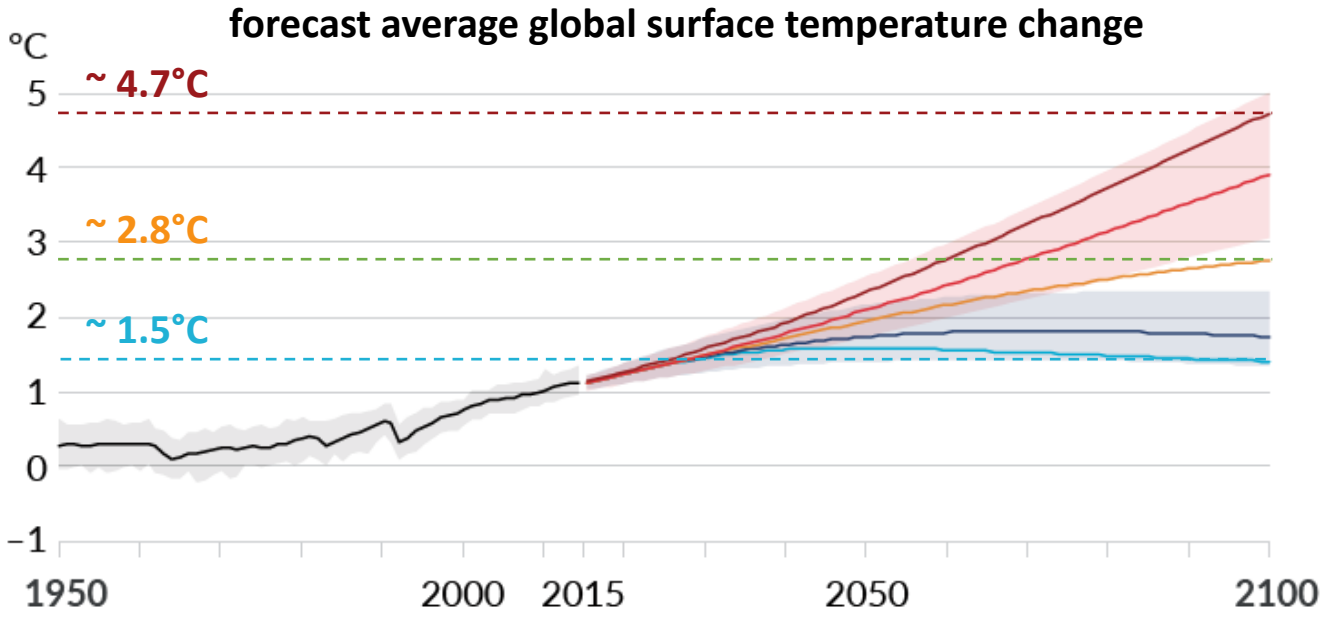
- **Meeting human needs in the present without compromising the ability of future generations to meet their needs**

17 UN Goals

#6, #7, #9, and #12 apply to tribology

Outlook on the Impact of Anthropogenic GHG Emissions





Global surface temperature will continue to increase until at least mid-century under all emissions scenarios considered. Global warming of 1.5 C and 2 C will be exceeded during the 21st century unless deep reductions in CO2 and other greenhouse gas emissions occur in the coming decades.

Source: 2021 Report by the Intergovernmental Panel on Climate Change –https://www.ipcc.ch/report/ar6/wg1/

CARBON FOOTPRINT CALCULATION - HOW CAN THE LUBRICANTS INDUSTRY GET THERE

Harmonized Industry Approach

- Industry agreed methodology build on international standards
- Establishing of consistent guidelines on boundaries
- Physical allocation on mass basis for non-energy products
- Hierarchy approach on data sources – primary data first!
- Independent assurance and verification
- Global cooperation and alignment

vsi-schmierstoffe.de

Publications Discussing How to Calculate LCA

UEIL

API –TR 1533

Both are referenced in the Trends Report

How to Reduce CO_2 Emissions and other GHG Emissions?

Answer: Decarbonization

GHG emissions produced by the combustion of fossil fuels must be significantly reduced

CO_2 present in the Earth's atmosphere must be absorbed through carbon capture and enhancing the ability of agricultural lands and forests to store carbon in an inert form

Move from a Carbon to a Hydrogen Economy

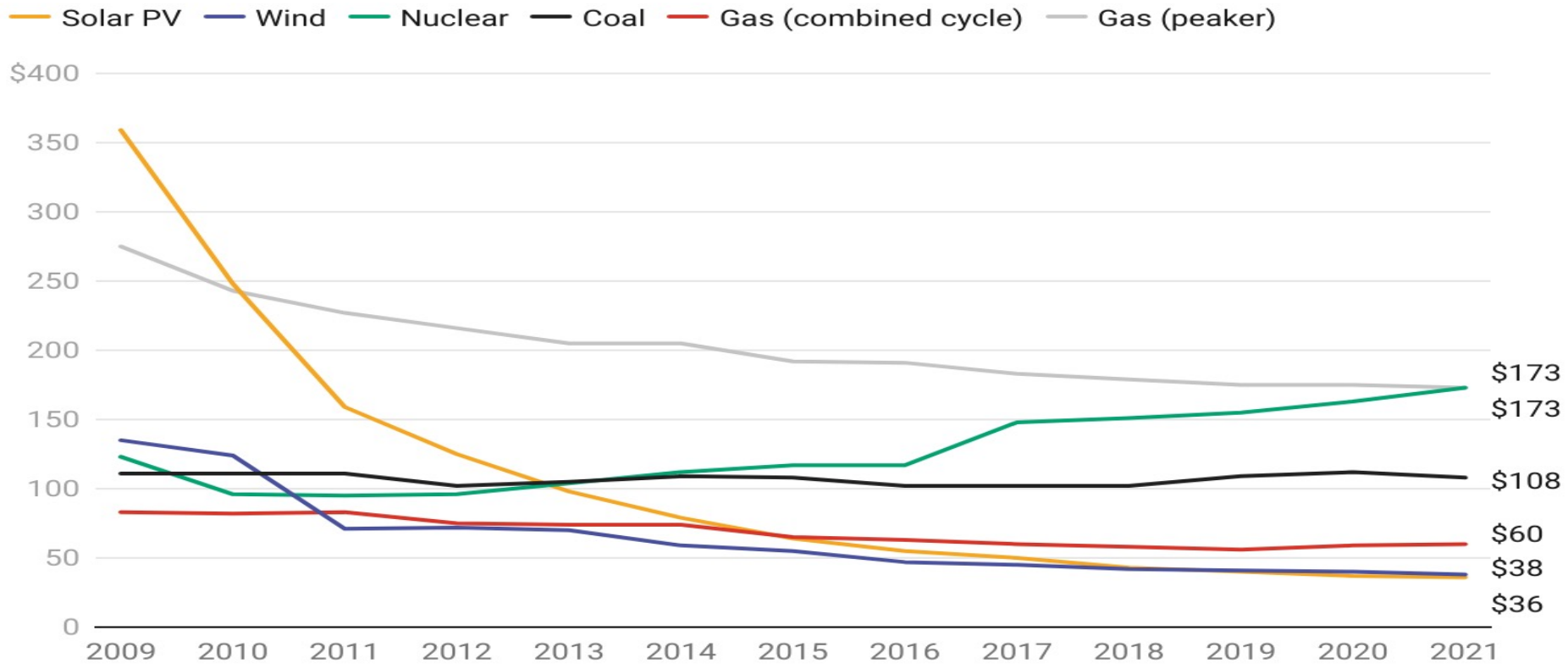
What Type of Hydrogen? Kaleidoscope of Options

Hydrogen Type	Description
*Green	Manufactured through electrolysis of water using renewable energy sources.
Blue	Produced from natural gas using steam reforming. Carbon dioxide is a by-product which will need to be captured and stored to minimize emissions
Grey	The most widely used process for manufacturing hydrogen. Natural gas or methane is put through a steam methane reformation but byproduct greenhouse gases are not captured.
Black and Brown	As the term suggests, hydrogen produced from coal, lignite or fossil fuel.
Pink	The energy source for producing hydrogen is nuclear via an electrolysis process
Turquoise	Hydrogen is manufactured using a methane pyrolysis process that also produces solid carbon
*Yellow	A relatively new designation for hydrogen produced by solar power
White	Geological hydrogen naturally occurring in underground deposits

Renewable Energy – Economics!

The falling costs of renewable energy

A comparison of the average levelized cost of utility-scale power generation, without subsidies, shows how new solar and onshore wind became less expensive than coal generation. Costs are in U.S. dollars per megawatt-hour.



Levelized cost of energy includes cost of construction and ongoing fuel and operating costs over its lifetime.

Chart: The Conversation/CC-BY-2.0 • Source: Lazard Levelized Cost of Energy Analysis

End User Sustainability Trends

- **Green Steel: 7% - 9% of CO_2 emissions – Electric Arc Furnace (EAF)**

End User Sustainability Trends

- Green Steel: 7% - 9% of CO_2 emissions – Electric Arc Furnace (EAF)

- **Aviation: 2.5% of CO_2 emissions – Sustainable Aviation Fuel (SAF)**

End User Sustainability Trends

- Green Steel: 7% - 9% of CO_2 emissions – Electric Arc Furnace (EAF)
- Aviation: 2.5% of CO_2 emissions – Sustainable Aviation Fuel (SAF)
- **Marine: 3.0% of CO2 emissions- EEXI in place to reduce GHG emissions by 40% by 2030**

What options are available for reducing the carbon footprint of a lubricant raw material?

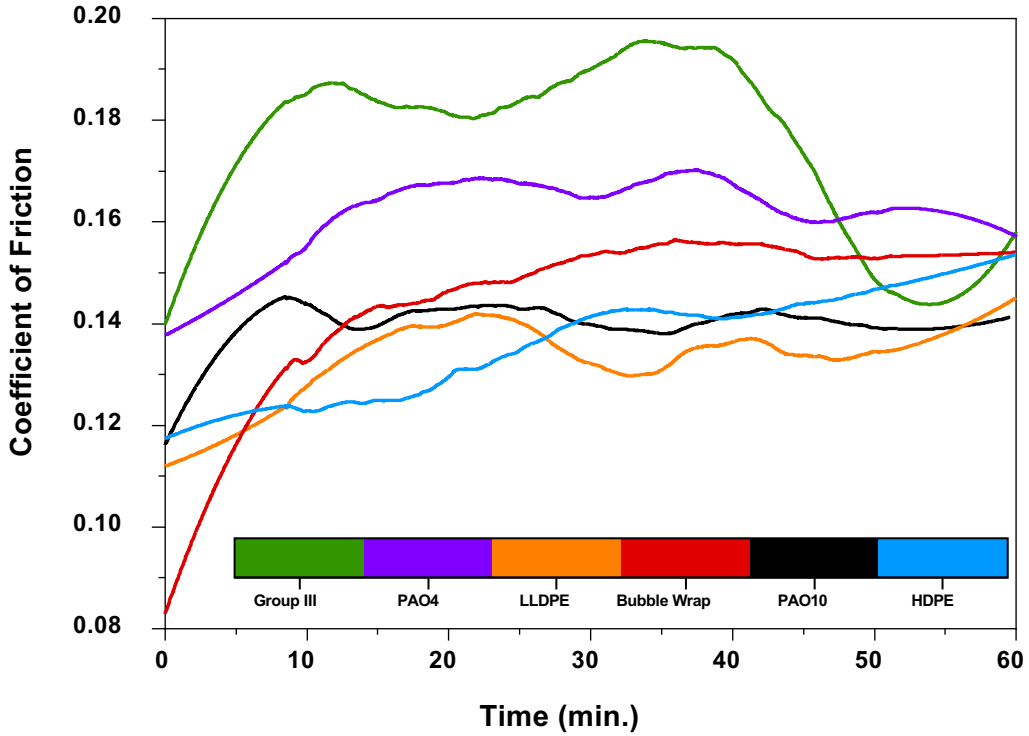
Potential Raw Materials

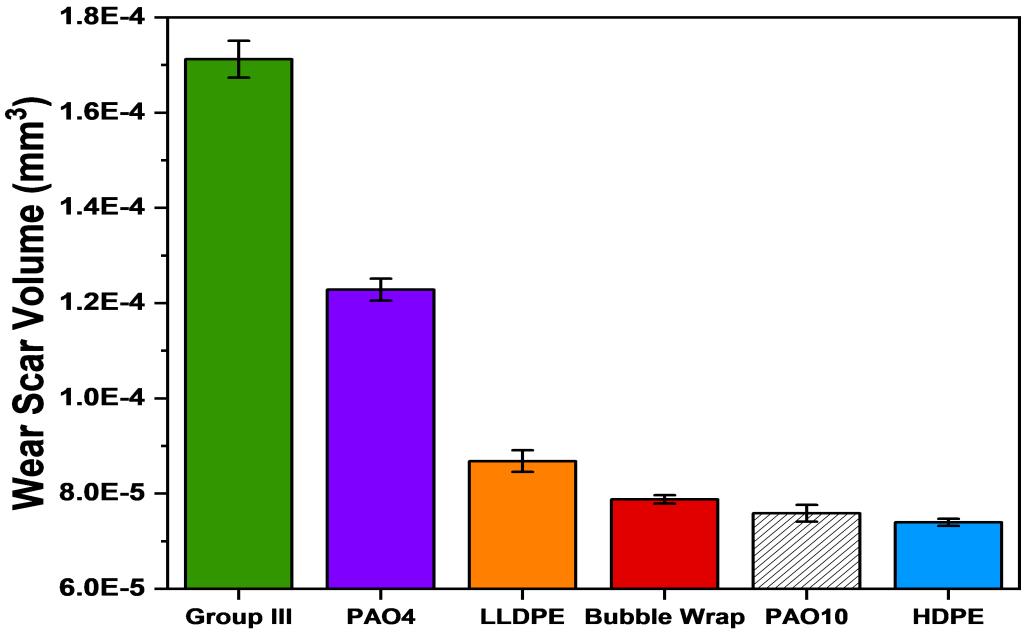
- Re-refined base oils
- Renewable raw materials (vegetable based
- Upcycling
- Objective: Circular Process (cradle-to-cradle)

Upcycling


NEW MATERIALS
from OLD PLASTICS
DISCARDED POLYMERS
Waste Plastic
Soaps
Shampoos
Cosmetics
Lubricants
CATALYST
UPCYCLING

Development of Potential Lubricant Base Stocks from Waste Plastic





One approach to determine the value end users place on sustainability

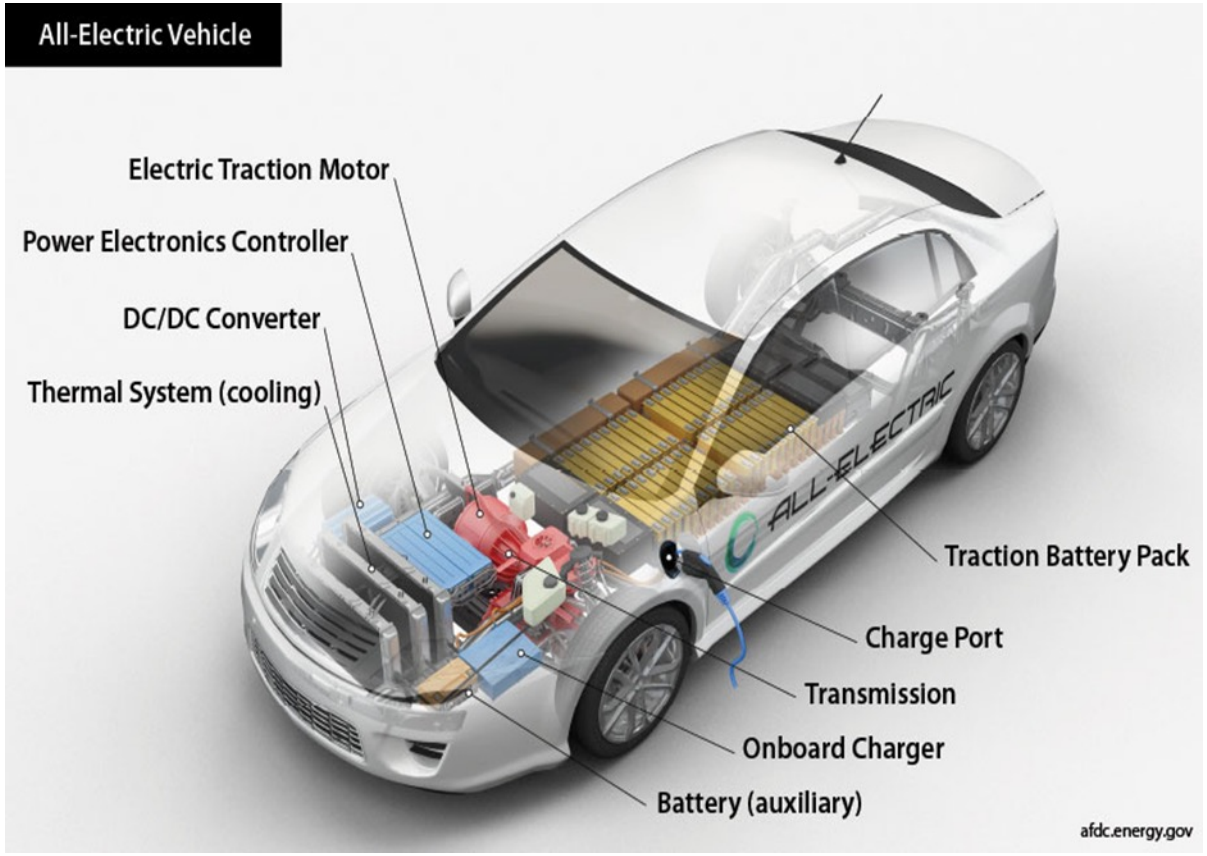
Sustainability Matrix - Emulsifiable Oil

Properties-Performance	0-20%	20-40%	40-60%	60-80%	80-100%	Weight
Productivity						
Energy Efficiency						
Environment/ Health						
Carbon Footprint						
Renewable Materials						
Low Consumption						
Long Sump Life						
Cost						

Fowler, R. (2023), “20 Minutes with” TLT 79 (12), pp 22 - 26

Electrification

Not just about Electric Vehicles



Electrification Trends

Growing demand for digital content → **internet use**

Increase in

Data centers

Growth of bitcoin mining

Growing Demand for Digital Services: 2015 - 2021

Category	2015	2021	Change
Internet users	3 Billion	4.9 Billion	60% increase
Internet traffic	0.6 ZB	3.4 ZB	440% increase
Data center workloads	180 Million	650 Million	260% increase
Data center energy use (excluding bitcoin mining)	200 Terawatts	220 – 320 Terawatts	10 – 60%
Bitcoin mining energy use	4 Terawatts	100 – 140 Terawatts	2300 – 3300 % increase
Data transmission network energy use	220 Terawatts	260 – 340 Terawatts	20 – 60% increase

Courtesy of IEA (International Energy Agency)

1 Terawatt = 1 Trillion Watts

Electric Vehicle Trends

Lubricant Selection

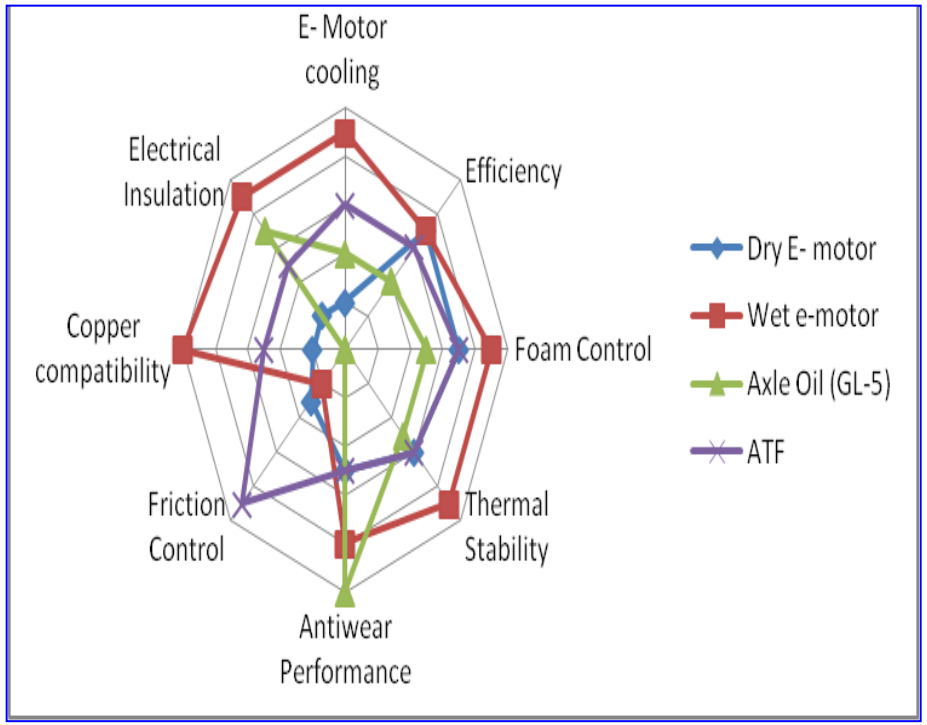
Battery Trends

Production: Impact on Metalworking Fluids

Lubricant Formulation Challenges

- Base stock and additives of composition package will determine the behavior of fluid in the electric field, will impact fluid aging
- Trends towards Lower viscosity for better heat transfer
- Maintaining Electric properties – right chemistry selection important
- EP Protection at high speed – Load carrying ability
- Oxidation and sludge control – Crucial for Oil drain interval
- Balancing Efficiency, Durability and NVH is critical – Traction / Antiwear / Film formation properties
- Compatibility with new seals / resin / coating / plastic

e-fluids vs conventional fluids



Tribology to play significant role in fluid design

Lithium-Ion Battery

- Anode (typically graphite)
- Cathode (various lithium metal oxides)
- Liquid electrolyte (organic solvents such as ethylene carbonate)
- Separator (polymer based typical polyolefins such as polyethylene)

Move from liquid electrolytes to solid state electrolytes

The Challenge for Industrial Lubricants in Moving to EVs

- Industrial lubricants needed to manufacture the components in an automobile
  - Powertrain (Engine + Drivetrain)
  - Body
- Fewer parts required to manufacture EVs than ICE powered automobiles
  - ICE Powertrain - >1,000 components
  - BEV Powertrain – 200 components

Reference: https://www.bcg.com/publications/2020/transformative-impact-of-electric-vehicles-on-auto-manufacturing

Suppliers Most Affected: Auto Parts Manufacturers

- Major users of metalworking fluids
- Conduct a variety of metal removal and metal forming operations
- Shift to electric vehicles: significant drop in demand for metalworking fluids and associated machine lubricants

Auto Parts Suppliers Contribution to Automobiles

- Internal Combustion Engines: Parts suppliers contribute 50 – 55% of the value
- Battery Powered Electric Vehicles: 35 – 40% of the value
- Largest impact – metal removal operations
  - Small chip operations such as honing, lapping and grinding

Reference: https://www.pwc.com/us/en/industries/industrial-products/library/electric-vehicles-supply-chain.html

Manufacturing of Internal Combustion Powered Automobiles – Engine Parts

- Cam shafts
- Catalytic converter housings
- Cylinders and cylinder heads – spark plugs
- Exhaust pipes
- Fuel injectors and pumps
- Mufflers
- Oil pumps
- Radiators
- Water pumps

Engine Blocks

- All engine components are in the engine block
- Generally made from die cast aluminum alloys

Largest application for metal removal fluids in ICE manufacture

Powertrain Parts

- Engine
- Clutches
- Transmission & Cases (Gears and Gear Sets)
- Drive Shafts
- Differentials (Gear & Gear Sets)
- Axles
- Brakes

In EVs, regenerative brakes will be used leading to less wear.

Critical Automotive Parts Affected by BEVs—Significant Reductions

Non- Ferrous Die Cast Parts

Stampings and Machined Parts

Engine Blocks	Fasteners Nuts & Bolts (less)	Radiators	Exhaust Manifolds	Valve train Components Springs Rocker Arms Valves	Fuel Tanks
Cylinder Heads	Camshafts	Exhaust Pipes	Drive Shafts Half shafts	Crank Shafts	Fuel Pumps
Engine block Front cover	Pistons	Mufflers	Turbo Chargers & Superchargers	Connecting Rods	Front Differentials
Transmission Cases	Gears Up to 20 per Transmission Plus shafts	Catalytic Converter Housings	Rear Differentials	Torque Converters & Clutches	Starter Motors

Body Parts

- Main supporting structure of an automobile
  - Bumper
  - Cabin parts
  - Frame
  - Hood

Mainly use metal forming fluids no change in usage anticipated in transitioning to BEVs

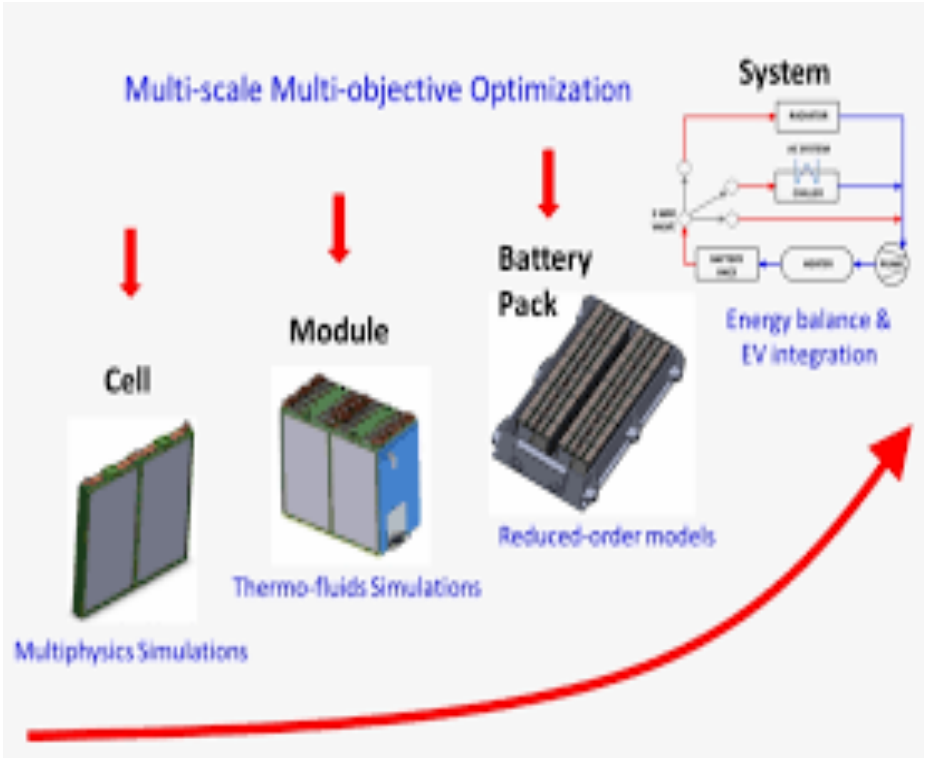
Electrochemical cells organized into modules

- Multiple cells in a case with battery terminals attached
- Number of cells used varies by EV manufacturer
- Range from 4 to 444 cells

Reference: Coffin, D. and Horowitz, J. (2018), “Supply Chain for Electric Vehicle Batteries US International Trade Commission - https://www.usitc.gov/publications/332/journals/the_supply_chain_for_electric_vehicle_batteries.pdf

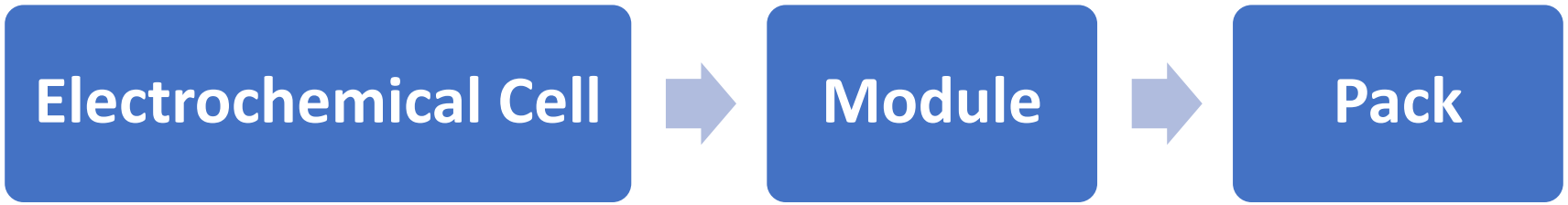
Battery modules organized into packs

- Battery packs contain
- Modules
- Electrical connections
- Cooling equipment

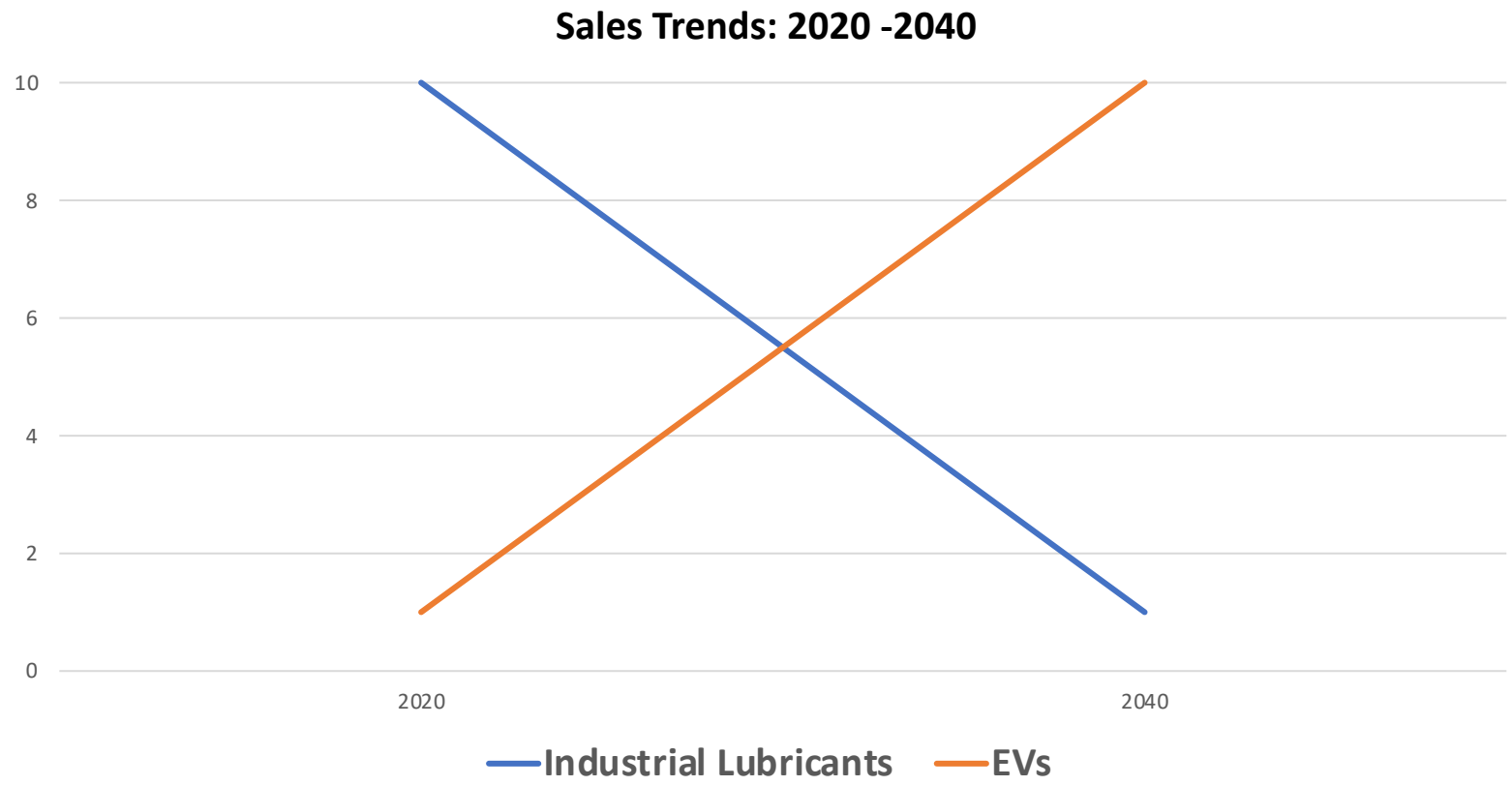


Main operation is stamping so metal forming lubricants are required

Battery Pack Manufacture



Electric Vehicle Sales Vs Industrial Lubricant Sales: “X” Marks the Spot



Two Other Automotive Propulsion Systems Using Hydrogen

- **Fuel cell**

- **Internal combustion engine – hydrogen is the fuel**

Manufacturing

Growing Use of Robots/Cobots

- **Robot density in manufacturing doubled between 2016 and 2021 to 141 robots per 10,000 employees**

Growing Use of Robots/Cobots

- Robot density in manufacturing doubled between 2016 and 2021 to 141 robots per 10,000 employees

- **Cobots interact with human beings**

Growing Use of Robots/Cobots

- Robot density in manufacturing doubled between 2016 and 2021 to 141 robots per 10,000 employees
- Cobots interact with human beings
- **Industry 4.0 [linking data, connectivity, automation, and artificial intelligence (AI)] is transitioning to include the human element (Industry 5.0)**

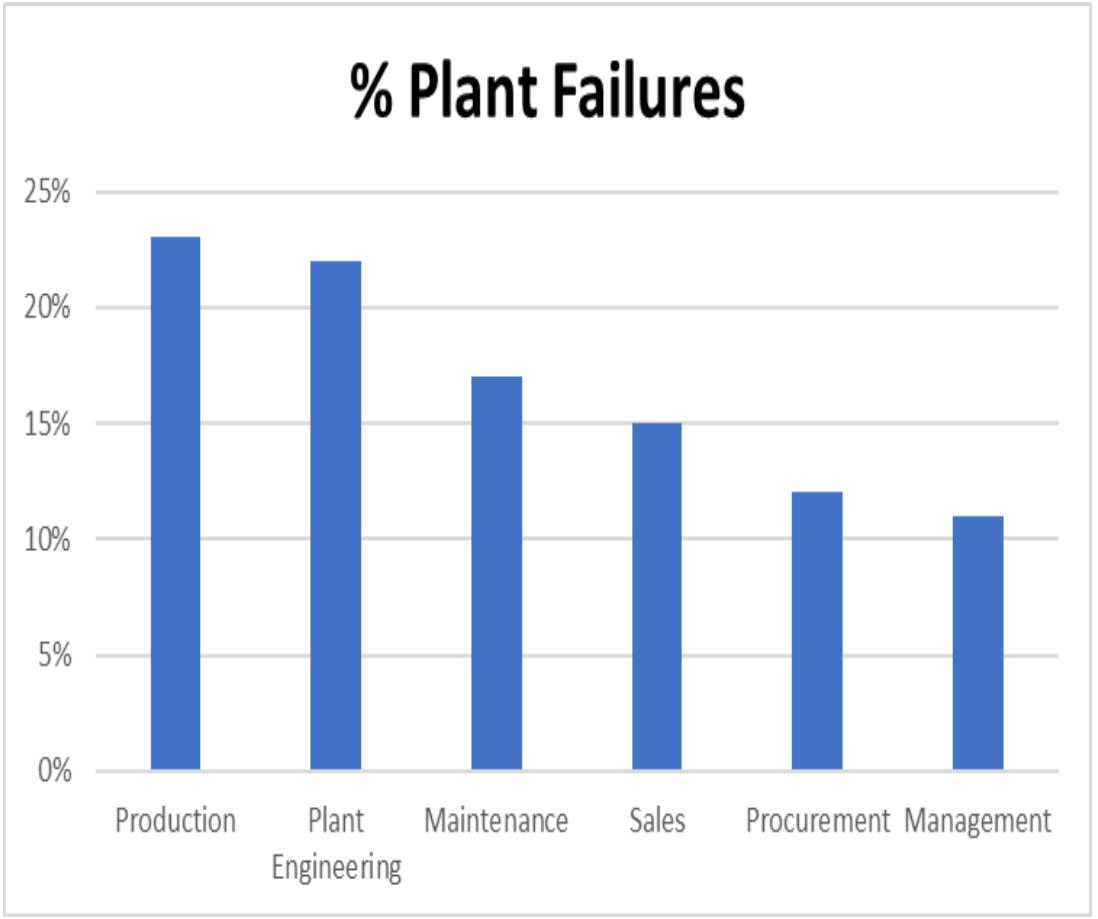
How do Tribologists Fit In?

- Train and program AI-based robots
- Utilize Machine Learning (ML)
  - Condition monitoring sensors
  - Work with molecular dynamics to eventually design new lubricants
- Eventually moving to tribotronics
  - “Controller” uses sensor data to make adjustments to a lubricant system
  - Predict friction and wear early in the use of a lubricant

Integration of Tribology and Sustainability into Manufacturing

- **Institute a reliability excellence program (R_x)**

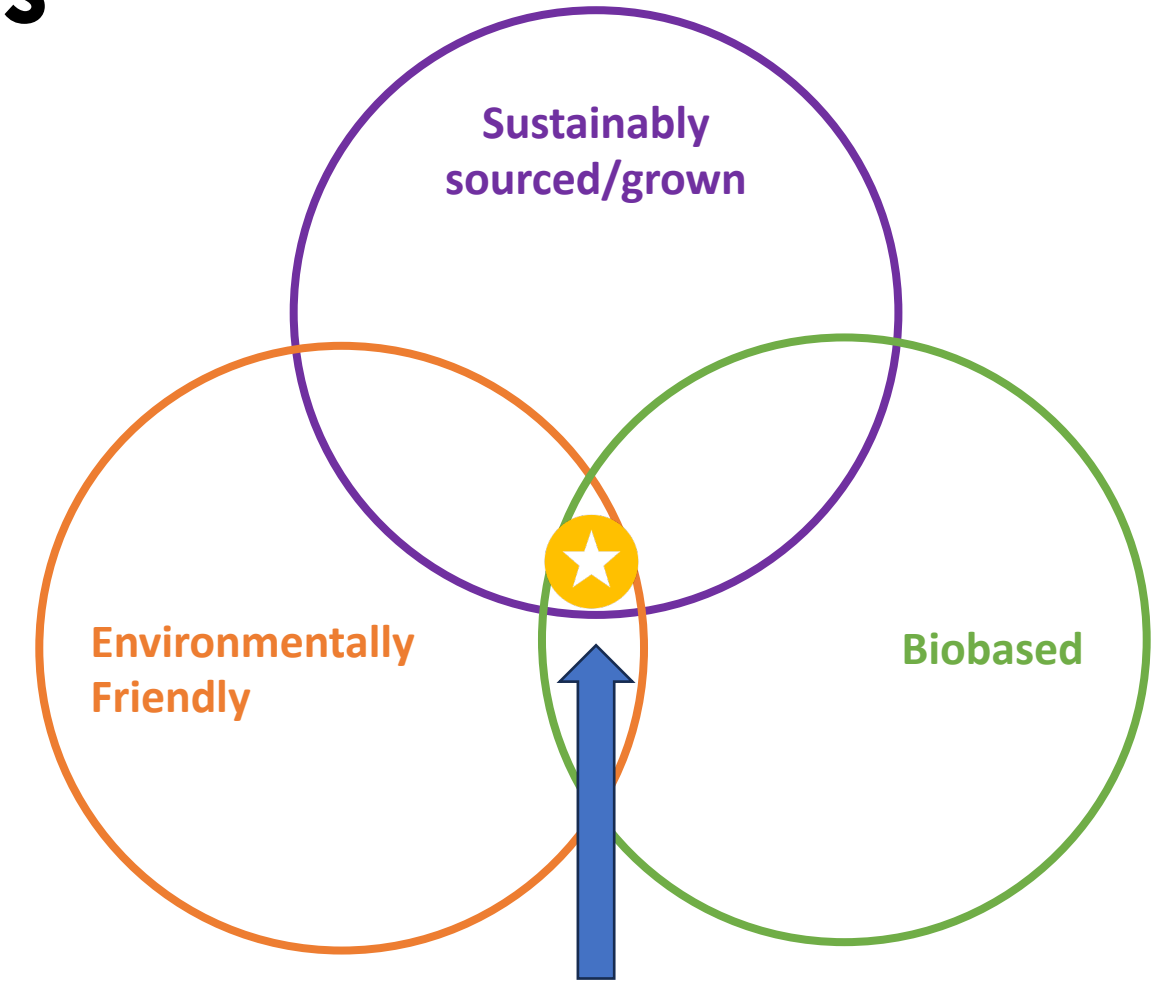
- **Look at leading causes of machinery failure**



Implementation of R_x

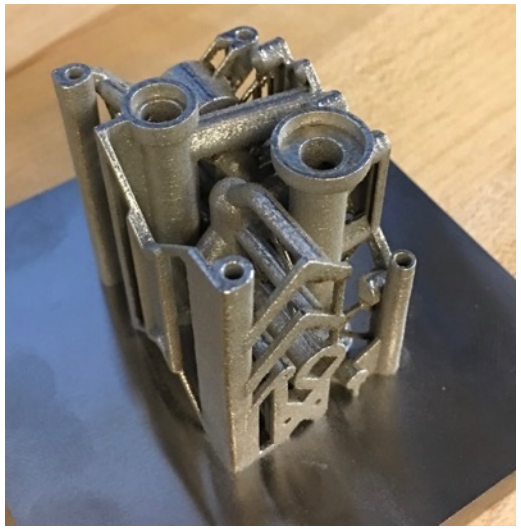
- Production-led reliability
- Proactive culture
- Metrics based performance
  - Including sustainability as a metric
    - Better performing lubricant reduces carbon footprint
      - Return on investment (ROI) is fairly quick – within months

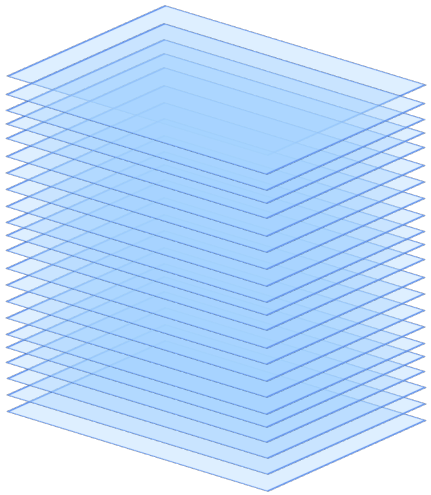
Better Performing Lubricants: Synthetic Lubricants



Find the Sweet Spot!

What is Additive Manufacturing?





- Break down complex 3D objects into simple 2D layers
- Build each layer on top of the previous

Advantages

- Less material waste
- Complex geometries
- No tooling required
- Design changes possible during production process

Disadvantages

- *High densities difficult to obtain, resulting in low part performance*
- *High-cost materials*
- *Slow build speeds*
- *Unsatisfactory repeatability*
- *Poor surface quality*

LEHIGH UNIVERSITY | P.C. ROSSIN COLLEGE OF ENGINEERING AND APPLIED SCIENCE

LOEWY INSTITUTE

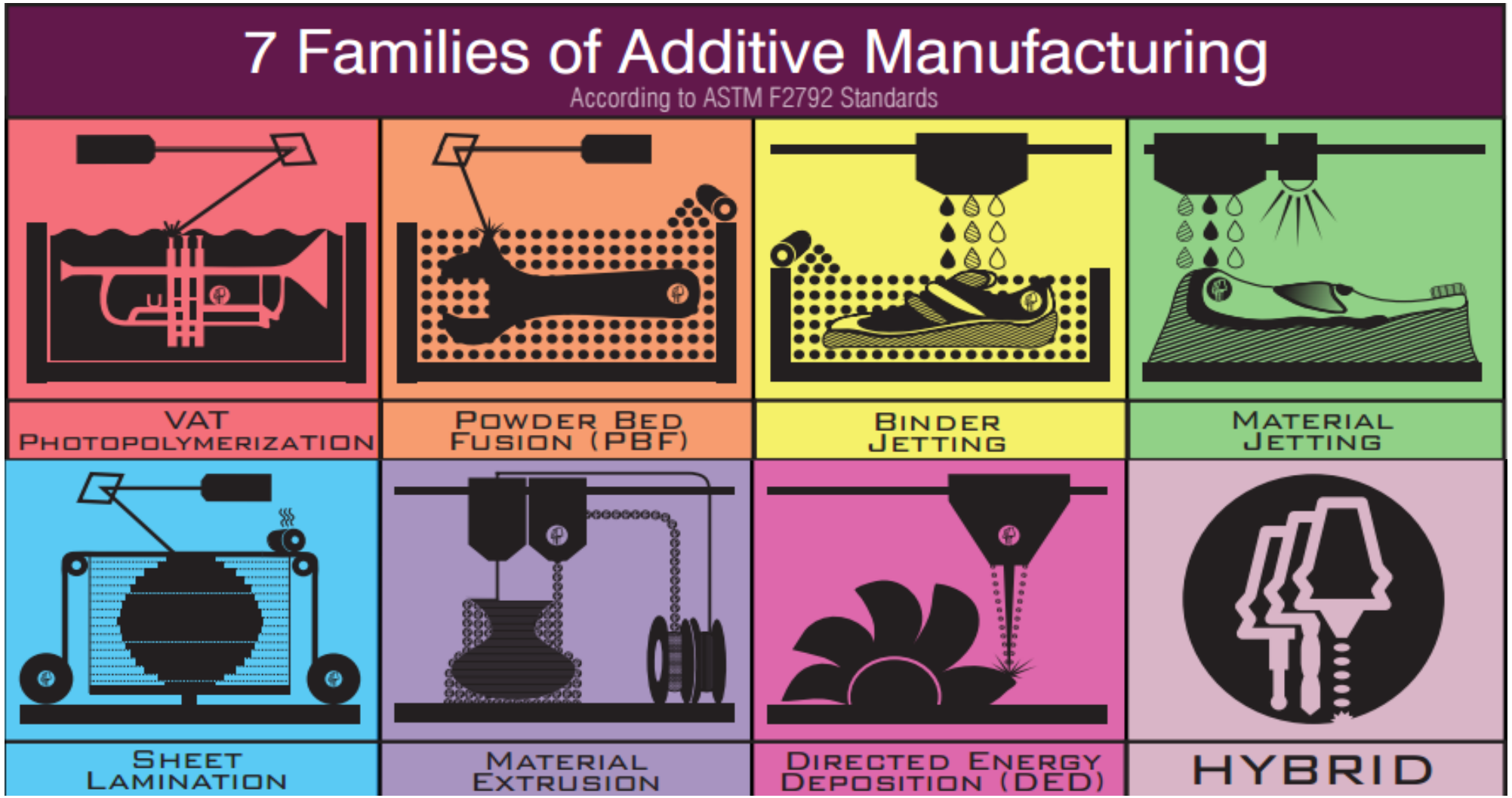


Image Courtesy of: Hybrid Manufacturing Technologies

Medical/Health

Tribology in use to gain a better understanding of how medical implants interact with adjacent cellular tissues

- **Ocular surfaces with soft contact lenses**
- **Silicon medical devices – breast implants**

Provide answers for how living cells deal with friction?

Objective develop water based lubricants to control interface between implants and cells

Government Regulations

- MARPOL
- Euro 7
- China 6b
- US Heavy Duty Truck Emissions
- Global Zero Emissions Vehicle Sales – by 2035

Government Raw Material Regulations

- Lithium salts – EU
- Biocides – US
- Boric acid – EU
- Chlorinated paraffins – EU, US and Canada
- PFAS – Per-and Polyfluoroalkyl compounds

Influence of Lubricant End Users

Sustainability is the key driver

- **Need to improve productivity**
- **Emissions and waste reductions**

Many technologies will need to be replaced to deal with global energy and climate challenges

Opportunities for Tribologists

End user sustainability demands fit well with the objectives of tribologists

Tribologists will be required to

- **Demonstrate how materials can meet sustainability and productivity objectives**
- **Demonstrate how lubricants can reduce carbon emissions**
- **Develop new type of materials and lubricants to meet challenging application needs**
- **Ultimately, effect meaningful change on achieving climate change and decarbonization goals**

Summary –Metalworking Fluids

- **Metalworking fluid use will decline due to transition to EVs**
- **Besides metalworking fluids (specifically metal removal fluids), other fluids to decline include hydraulic fluids, gear oils, way lubricants, heat treat (quenching) fluids and die caste fluids**
- **Demand for metal forming fluids used to manufacture battery casings and copper wire will increase**
- **Opportunities will present themselves in other manufacturing sectors where newly developed metalworking fluids can improve productivity, reduce emissions, and improve sustainability**

QUESTIONS?

Acknowledgements

STLE Past President, Dr. Ryan Evans

AIT Past Chair, Dr. Nic Argibay

AIT Current Chair, Dr. Aaron Greco

AIT

The STLE Board of Directors

All of the Contributors

STLE Past Executive Director, Ed Salek

Q&A