Building the Next Generation Electric Drive Fluids (EDFs) for Enhanced Energy Efficiency

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AGENDA

- Background
- Building the candidates
- Efficiency Testing
- Performance Beyond Efficiency
- LCA Story
- Summary

INTRODUCTION TO NOVVI

Novvi's mission revolves around creating the **highest-performing products** in the industry. Our collaborative culture allows us to respond to industry needs for unique solutions.

We create **highly tailored synthetic hydrocarbon base oils** to meet increasingly challenging application requirements. Novvi optimizes the structure and branching of our hydrocarbon base oils to control critical fluid properties.

Novvi is dedicated to creating products that **reduce greenhouse emissions** produced from ethically sourced renewable feedstocks.

AFTON CHEMICAL

1924
Ethyl Gasoline Corporation formed

2004
NewMarket Corporation formed

Afton CHEMICAL

2022
Afton today

A key player in the lubricant and fuel additive industry for more than 95 years.

$2.3 B turnover; ~1,925 employees

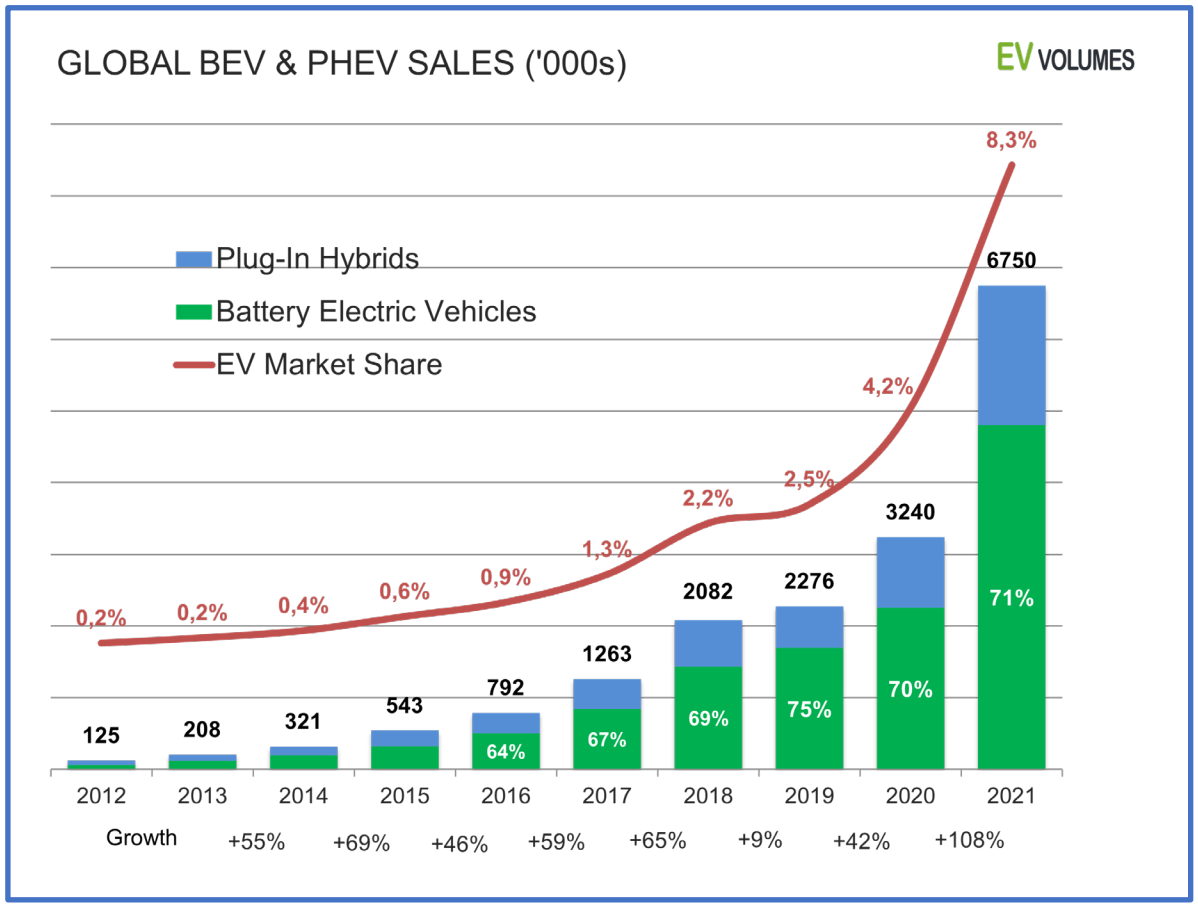
- Afton has a long history in the petroleum additives industry
- A global company with:
  - 9 manufacturing plants
  - 5 R&D facilities
  - 22 Sales offices

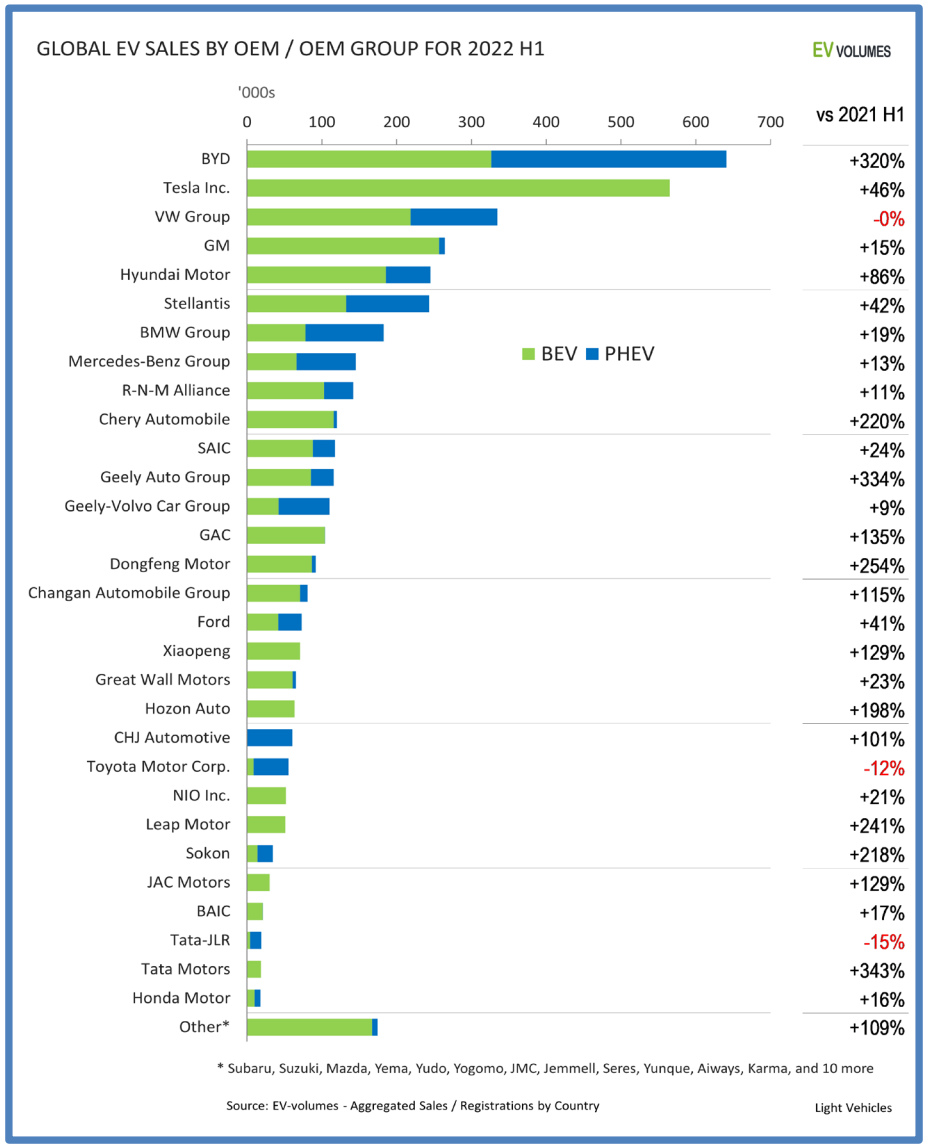
- Our Mission Statement:
  - Make the world a better place by providing technology solutions – globally – that make vehicles more efficient, machines last longer, and fuels burn cleaner; while achieving profitable growth
- Our Philosophy: Passion for Solutions
  - It emphasizes that it is the inspiring and enthusiastic people who – when combined with our expert and innovative chemistry – deliver effective solutions for our customers, helping them achieve their business goals.

novvi™

Afton CHEMICAL

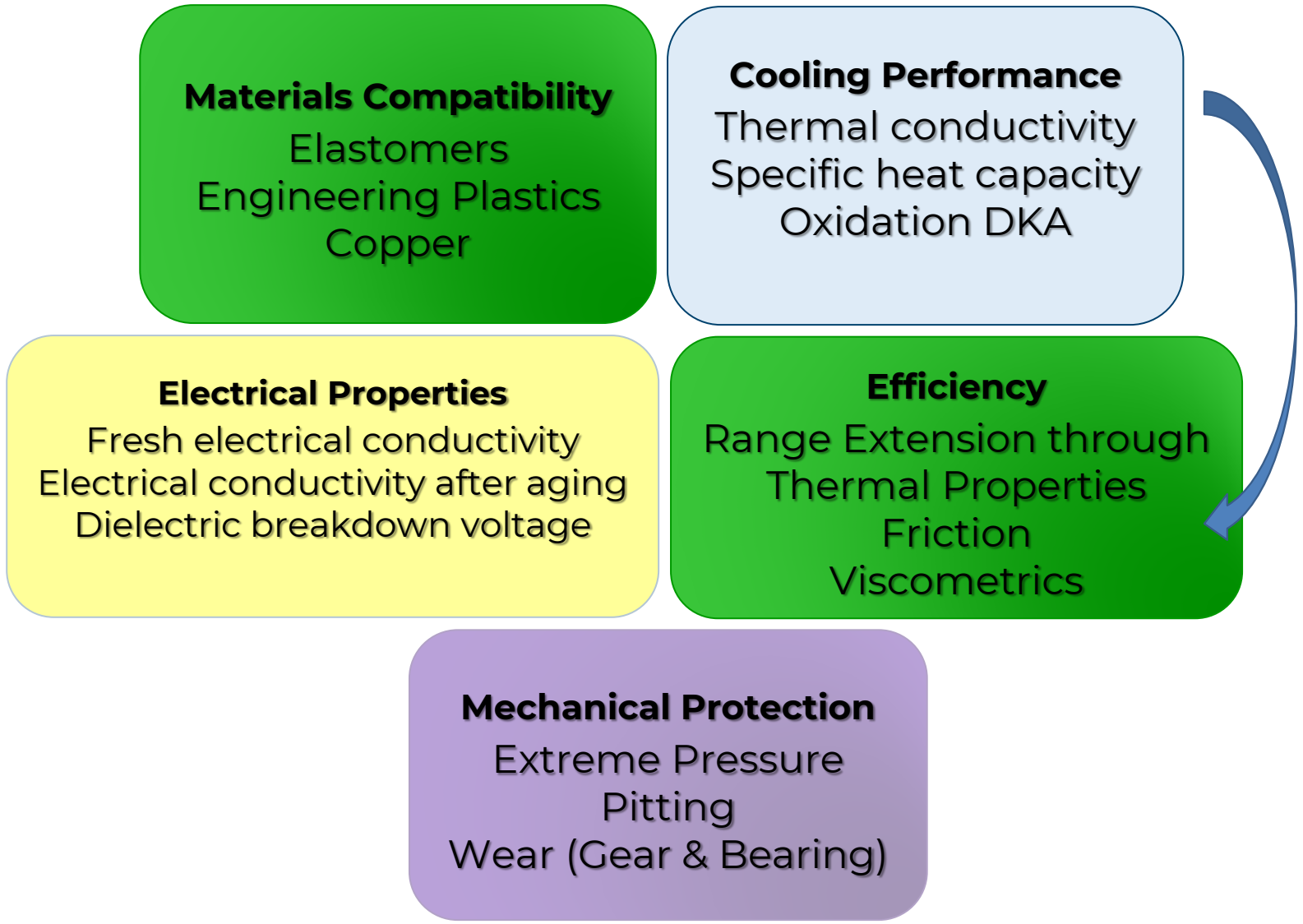
THE TRANSITION TO BEVs IS UNDERWAY & ACCELERATING



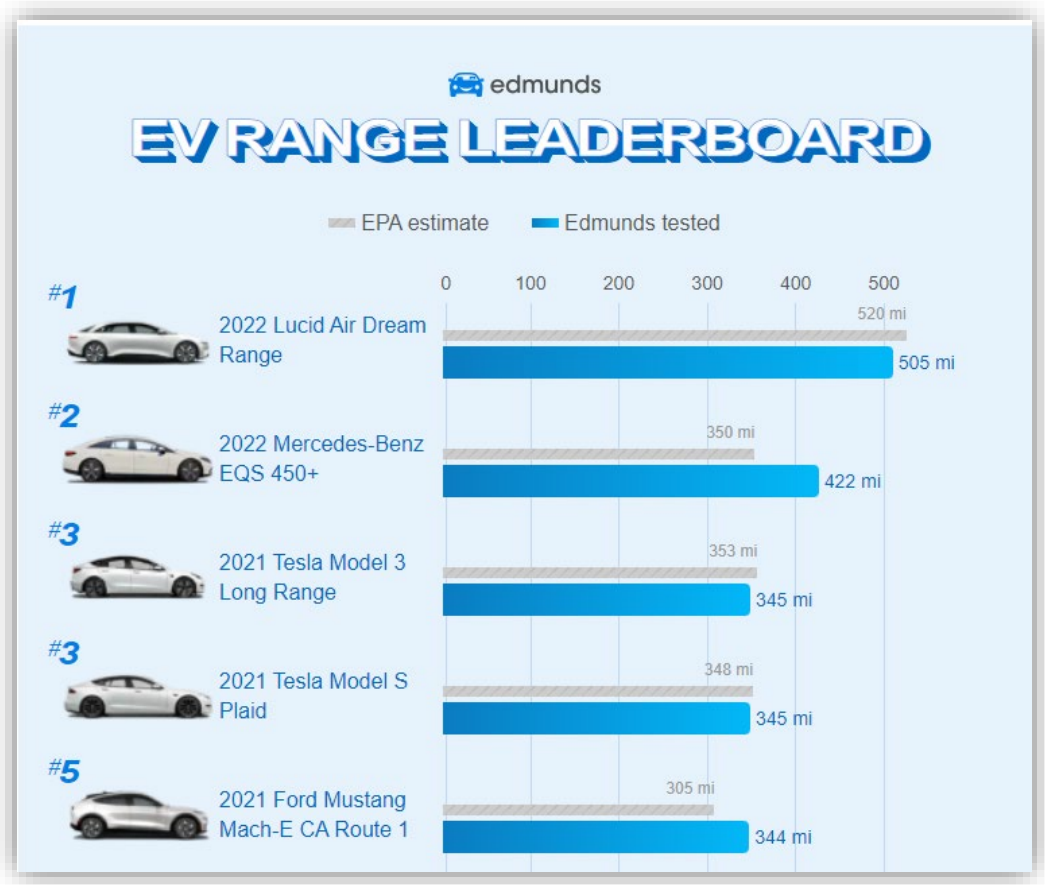


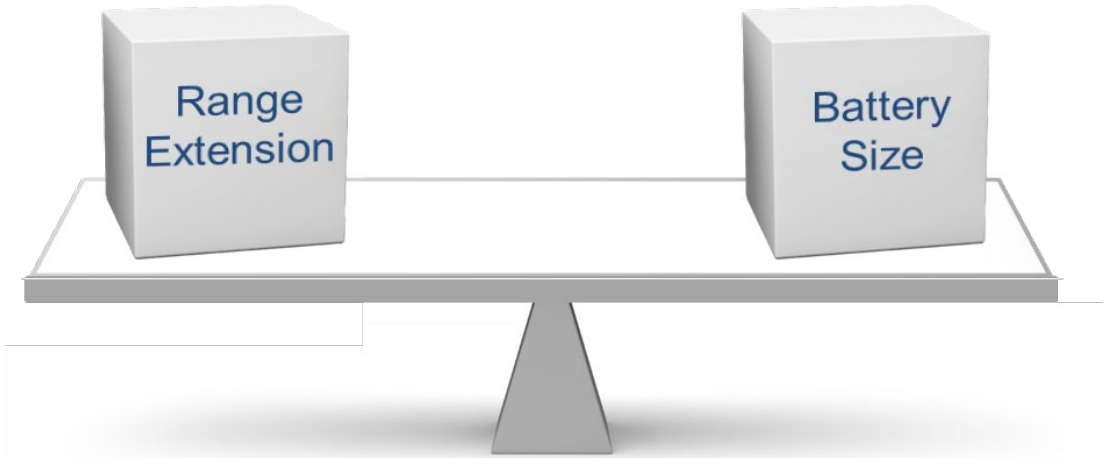
ELECTRIC DRIVE FLUID DEVELOPMENT

- Electric Drive Fluids (EDFs) are comprised of a synergy between the Base Oil + Additive Technologies
  - Each imparts specific properties to the fluid
  - Optimum performance is a balance of all components
  - The right additive technology allows use of new high performance base oil technology



WHY IS EFFICIENCY IMPORTANT?





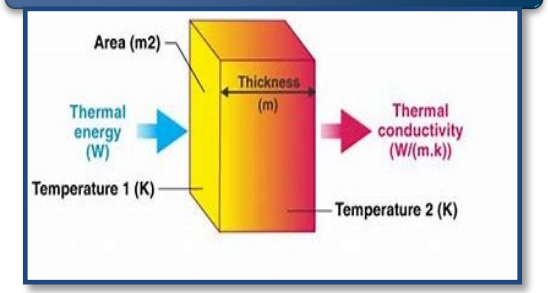
- Consumers want BEVs to go farther on a single charge
- Consumers (and OEMs) also want less expensive BEVs

Less power loss thru the electric drive unit means more battery power is available for EVs to go farther on a single charge

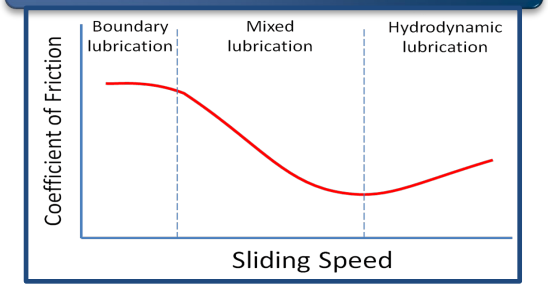
Alternately, higher efficiency allows OEMs to reduce battery size (and cost) while maintaining the same vehicle range

FLUID PROPERTIES THAT DRIVE EFFICIENCY

Thermal Properties



Friction/Traction

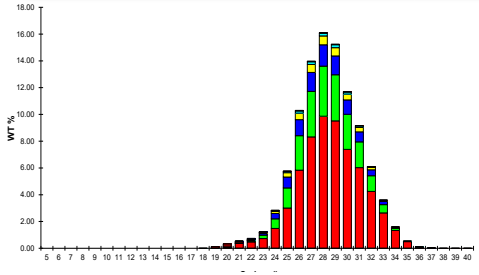


- Dominated by base oil chemistry and structure
- Linearity and uniformity raise thermal conductivity and lower traction

Viscometrics

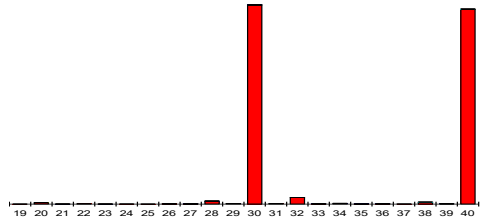
- Influences thermal and friction properties
- Lower viscosity reduces churning losses

Group III



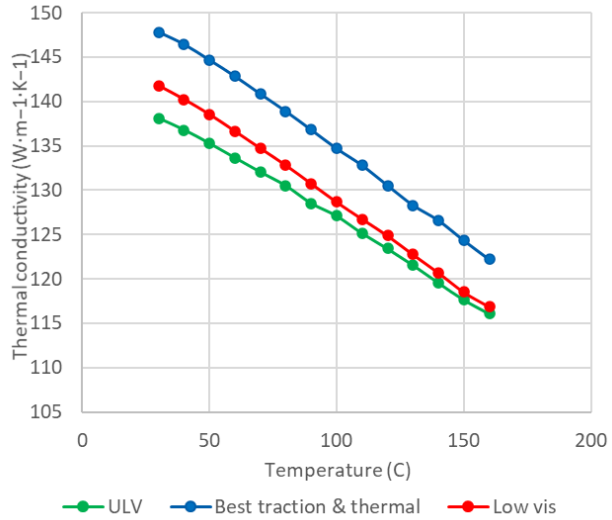
Random mix of saturated rings, iso-paraffins and n-paraffins

Group IV (PAO)

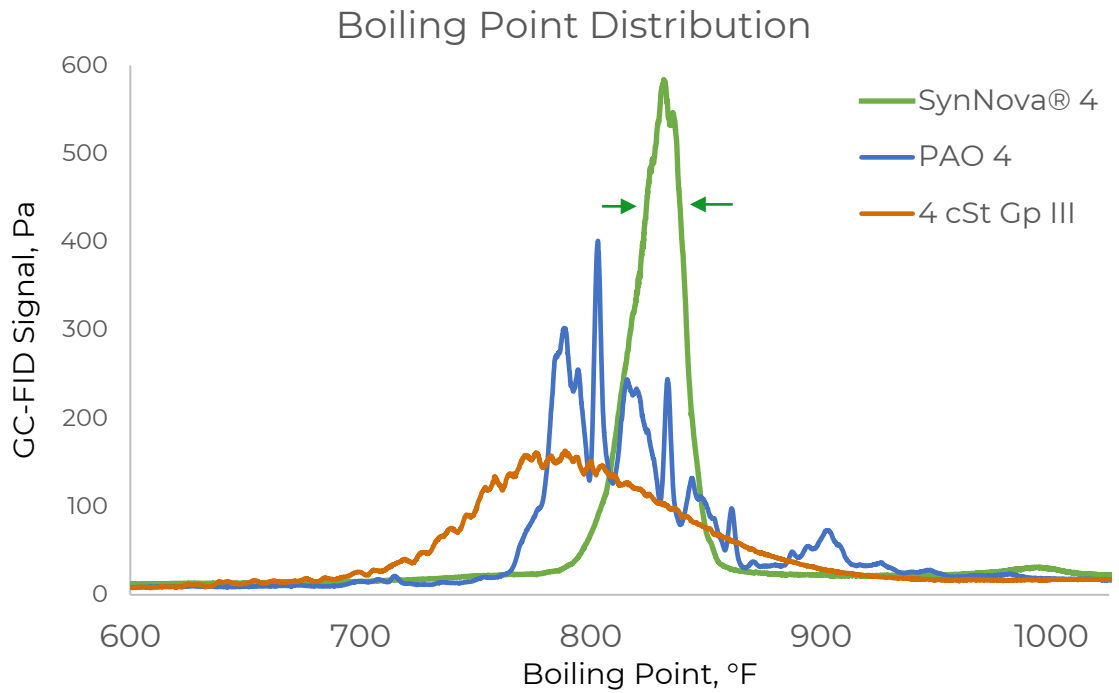


Well-defined mix of iso-paraffins

Thermal Conductivity Example



SUSTAINABLE SYNTHETIC HYDROCARBON BASE OILS



Grp III: mixture of isoparaffins, n-paraffins and ring saturates

PAO: all isoparaffins

SynNova® : renewable isoparaffins with a different branching optimization from PAO

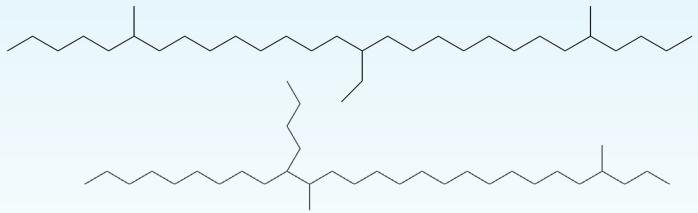
Novalon™: Renewable isoparaffins with a branching optimization for reduced coefficent of friction

Novvi's manufacturing process allows for precise control over the base oil's branching and physical properties.

Novvi can control key properties critical to ETFs:

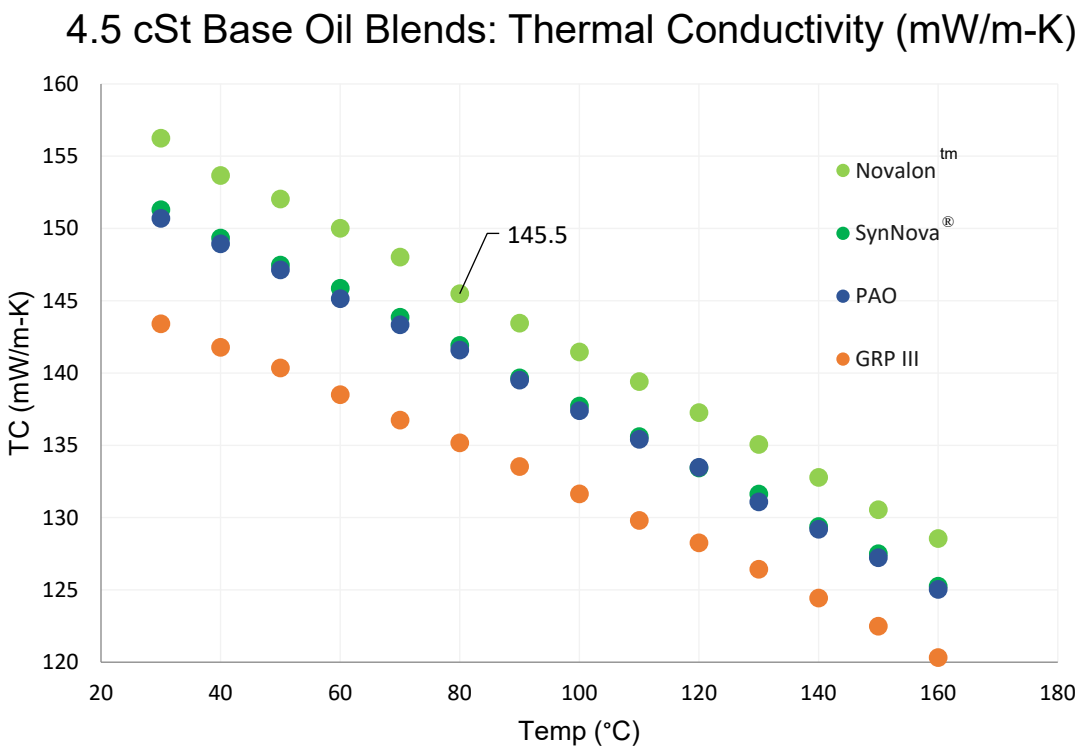
- Thermal conductivity & Heat capacity
- Oxidative stability and low volatility
- Coefficient of friction

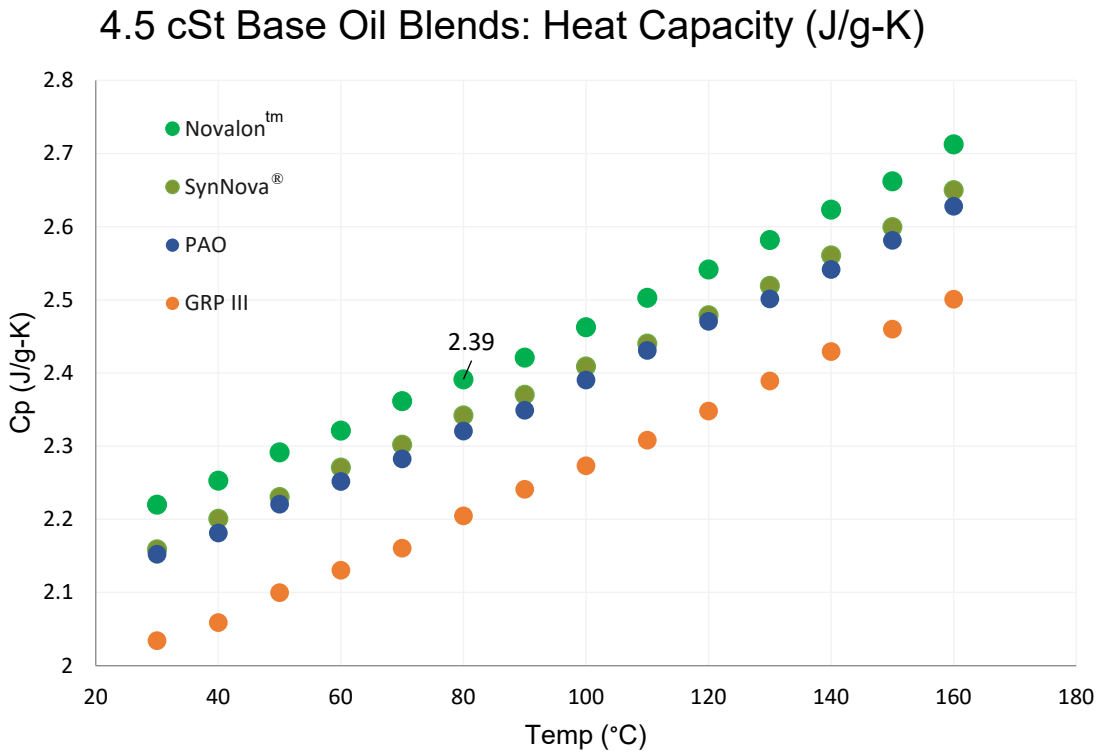
SynNova® Representative Structures



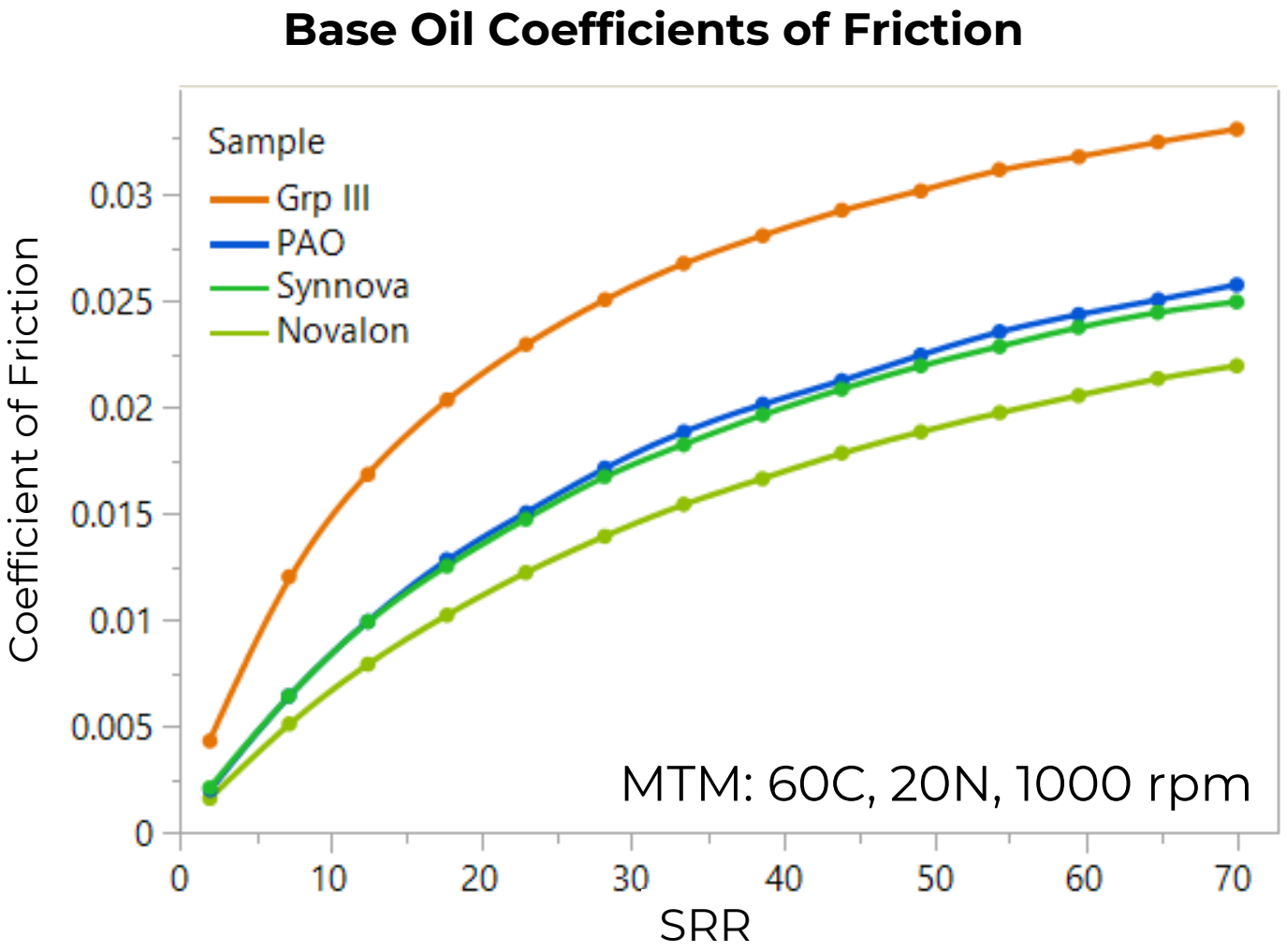
CONTROLLING BASE OIL STRUCTURE CAN IMPROVE TC & HC

- Isoviscous base oil comparison takes out MW effect on static thermal properties
- Novalon delivers the Highest Thermal Conductivity and Heat Capacity possible in a hydrocarbon base oil





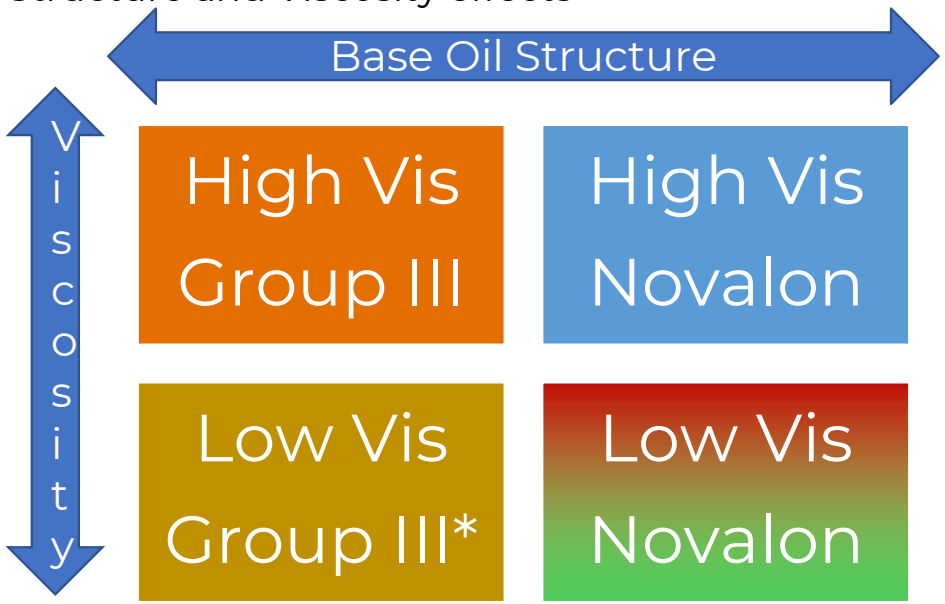
EFFECTS OF HYDROCARBON BASE OIL STRUCTURE COEFFICENTS OF FRICTION



- Although all the base oils compared are hydrocarbons, changing the branching and structure greatly affects the coefficient of friction
- The coefficient of friction has been shown to correlate with EDF drive unit efficiency
- Base oil selection is critical for reducing the coefficents of friction for the most optimal EDFs

FUNDAMENTALS OF EFFICIENCY : BUILDING THE CANDIDATES

In this study, the main drivers explored: Base Oil Structure and Viscosity effects



*Low Vis Group III not included

Component	6cSt ATF Baseline	6 cSt ETF (w/ Novalon)	6 cst 50:50 GrpIII & Novalon 4 ETF	4.8 cSt ETF (w/ Novalon)	3.8cSt ETF (Exp Low Vis)
ETF Addpack + VM					
Novalon 4		76.9	38.45	94.5	
Grp III 4 cSt			38.45		
Next Gen Low Vis					94.0
Synnova 9		15.0	15.0		
KV100	6.0	6.0	6.1	4.78	3.78

How low is too low? While lower viscosity generally lowers coefficient of friction and churning losses, you may run into limitations around

- Flash point
- Film thickness and wear & pitting
- Water absorption, maintaining low conductivity
- Materials compatibility of any exposed elastomers

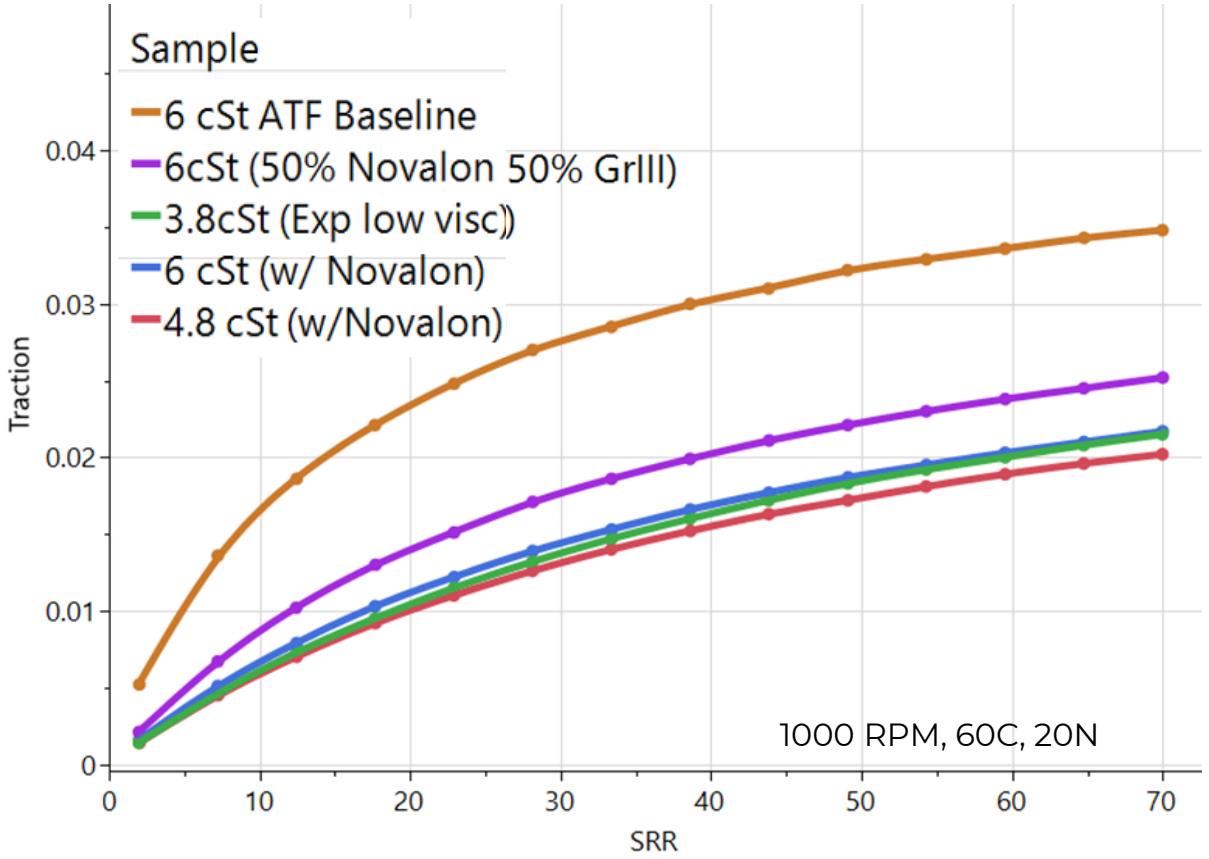
Role of the Additive Formulation

Highly dependent on the hardware and thermal management system for each OEM

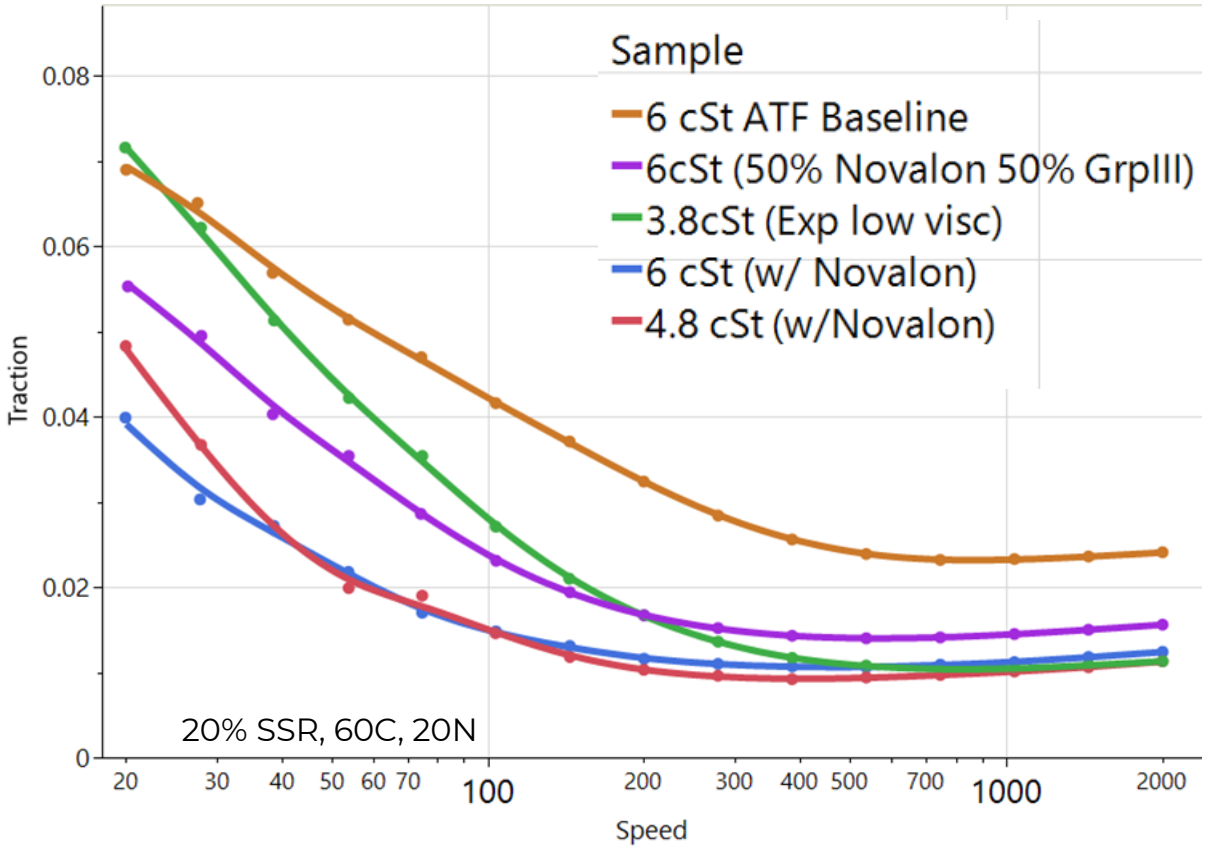
SCREENING THE CANDIDATES

- Reduced friction reduces loss in EV-drivetrain and increases miles per charge
- The linear structure of Novvi base oils reduces COF across the Stribeck curve on MTM

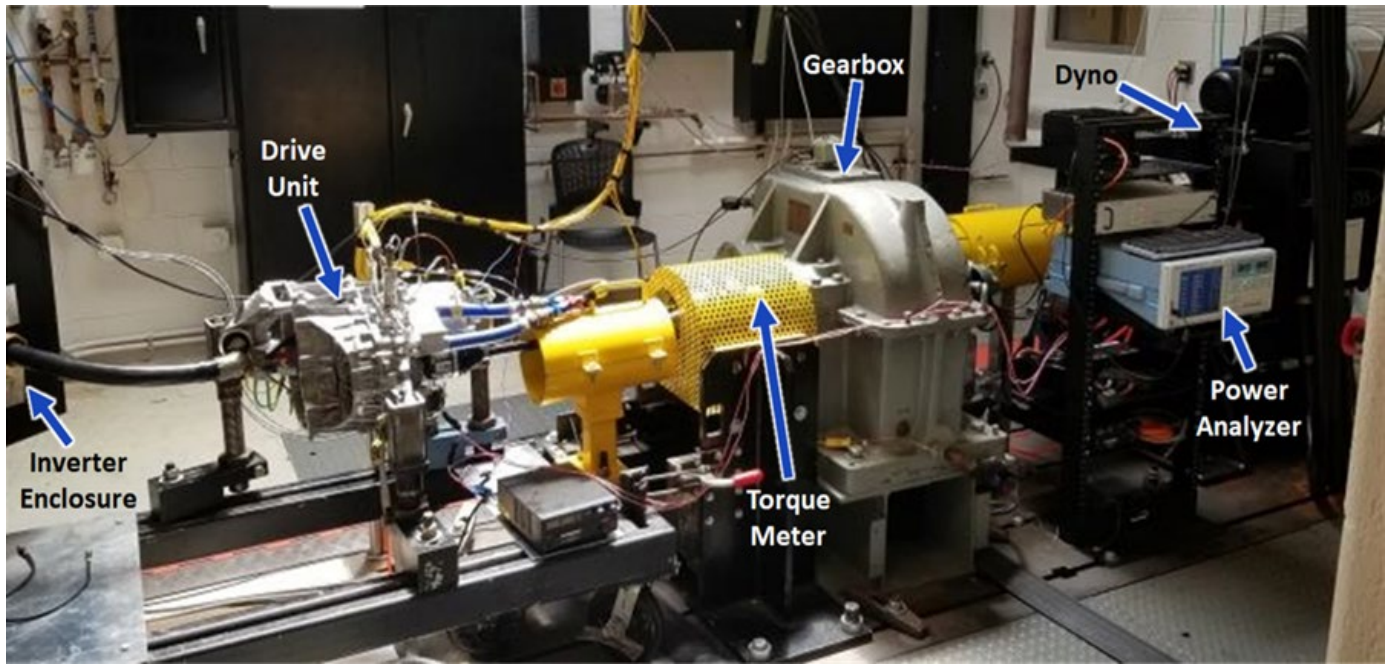
Traction Curve



Stribeck Curve

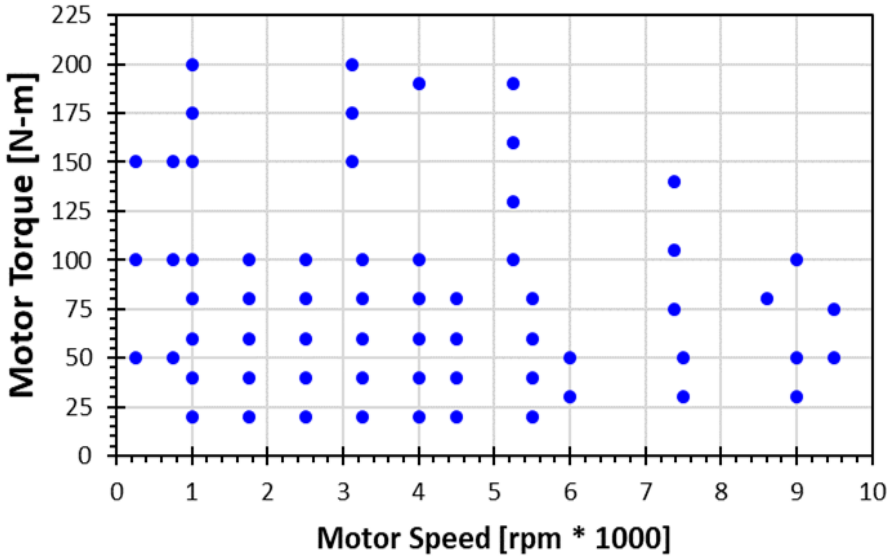


EFFICIENCY BENEFITS IN MODEL 3 DRIVE UNIT



Efficiency Testing Set Points

15-second settling time 15-second data-averaging window

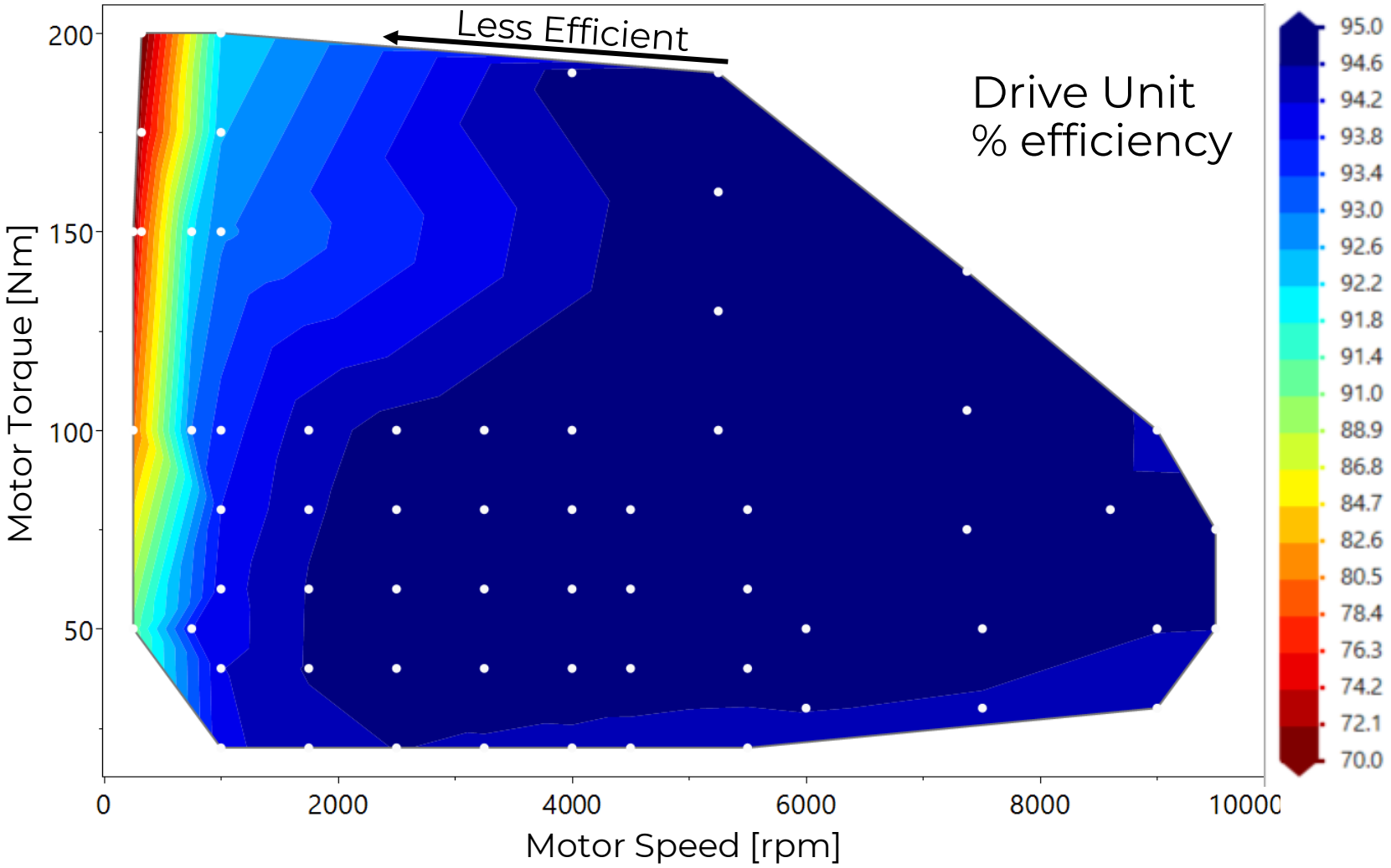


Efficiency Testing Data

- 63 static torque vs speed points tested
- Each fluid tested 8 times at each set point
- Baseline was run in triplicate

VISUALIZING 6cSt BASELINE ATF (Grp III) EFFICIENCY

6cSt Baseline (Grp III) %Efficiency on Model 3 Drive Unit

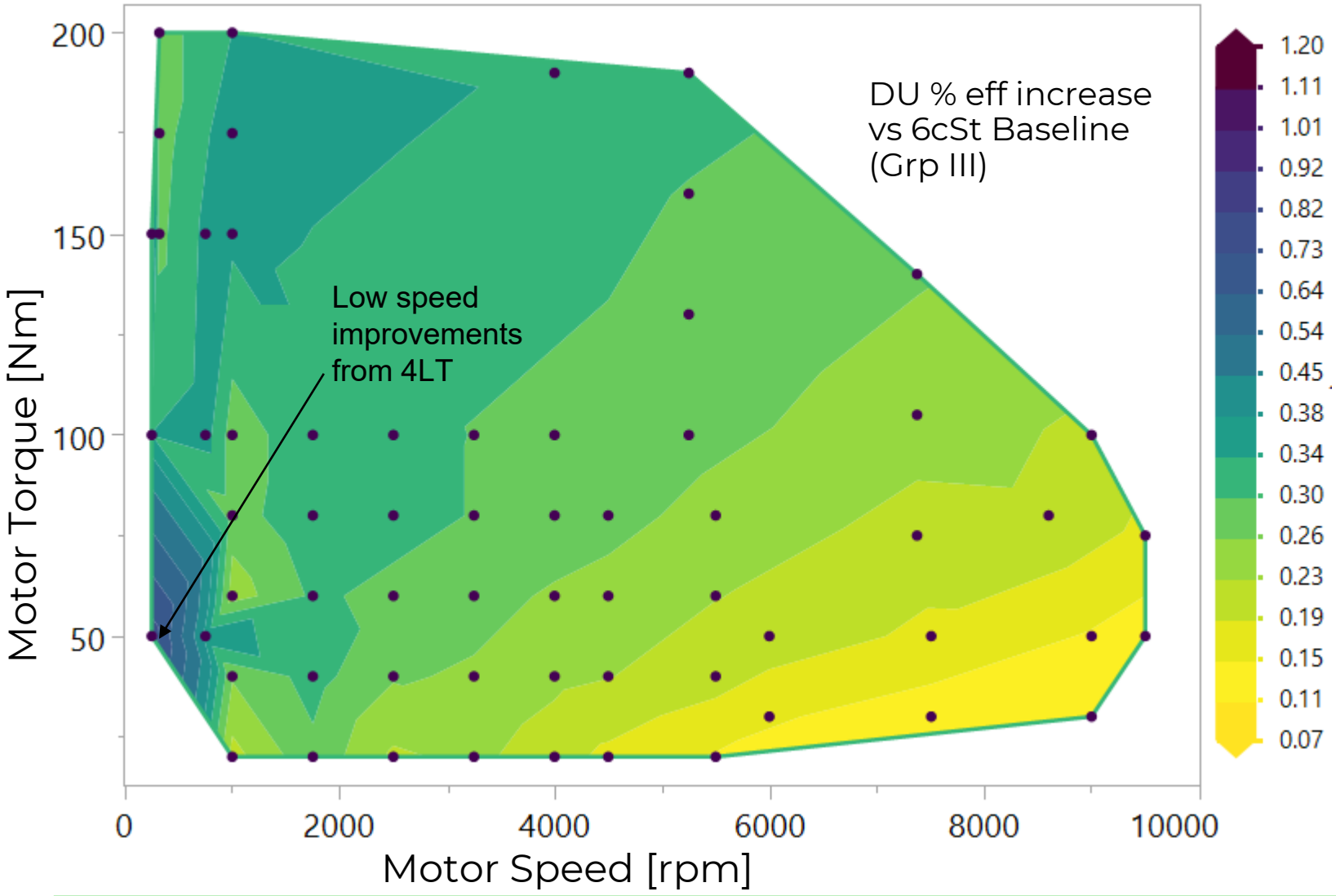


Efficiency measurement for 6cSt Baseline (Grp III) ATF fluid

- Lower speed and higher torque points have lower efficiency
- Mid range speed and torque points have >95% efficient
- 63 points are used as reference points for each formulation tested

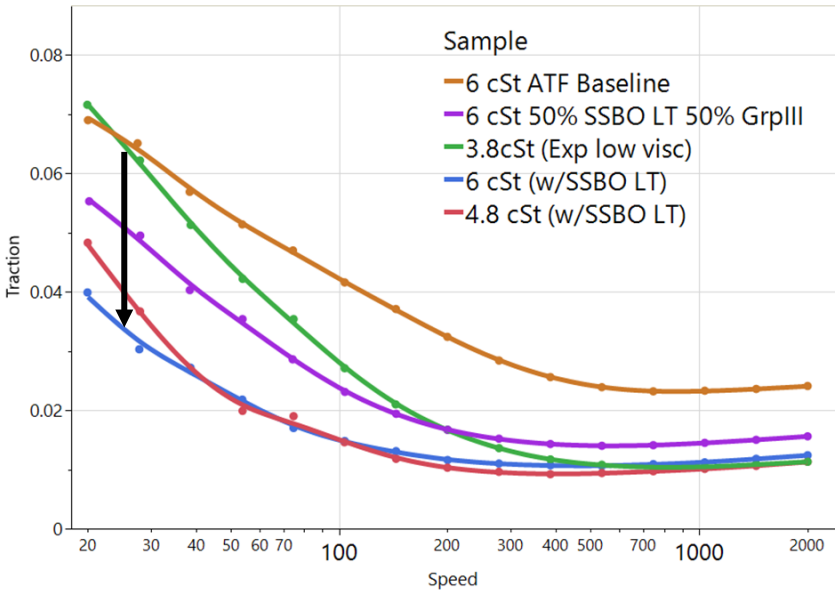
MODEL 3 DRIVE UNIT EFFICENCY BENEFIT FROM NOVALON IN A 6 CST EDF

ΔEfficiency of 6 cSt w/ Novalon over 6 cSt Baseline (Grp III)



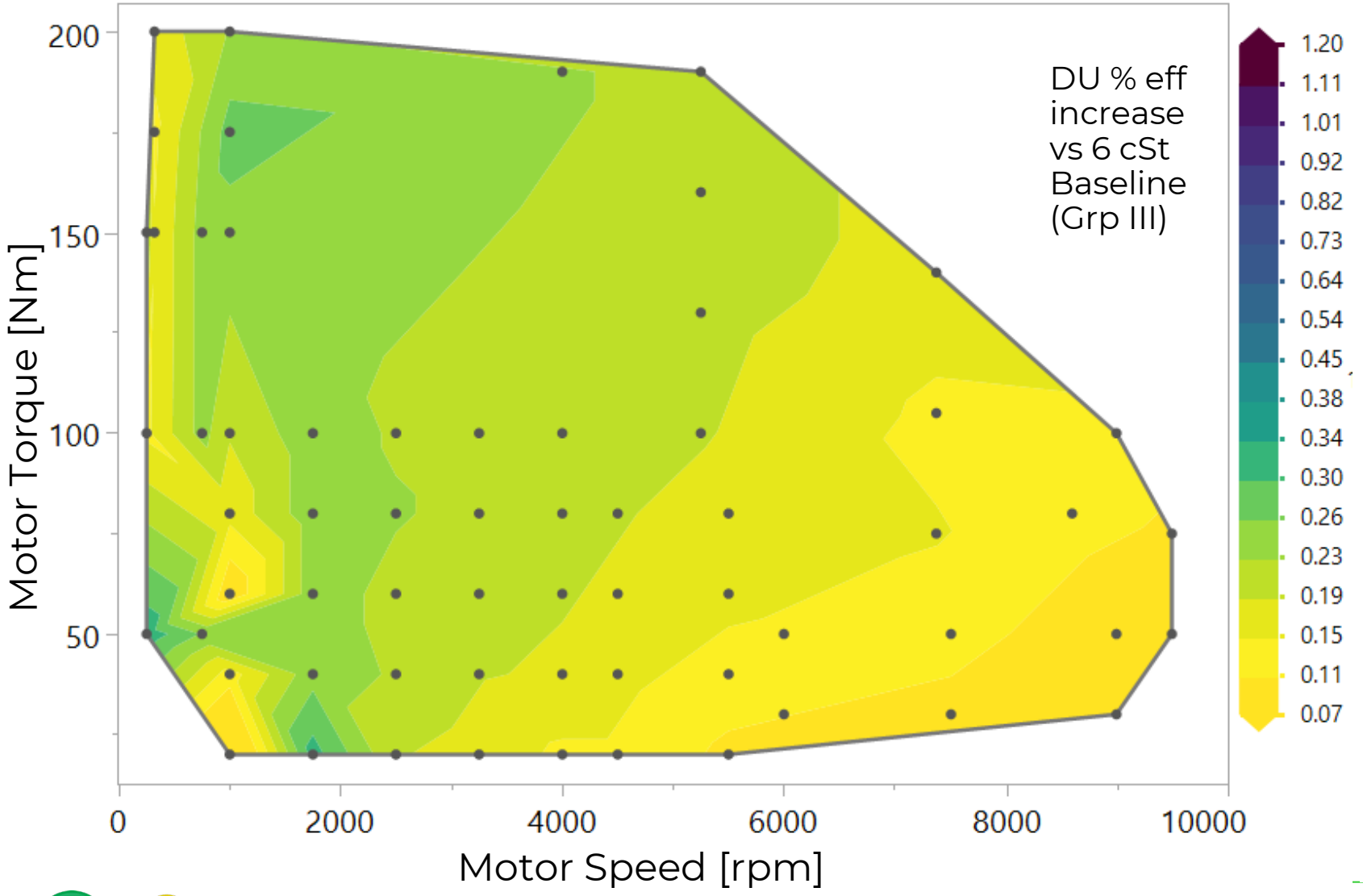
Changing base oil structure improves drive unit efficiency – even at the same finished fluid viscosity

- Low motor speed shows higher efficiency gains correlating to low-speed COF reductions seen in stribeck curve measurements



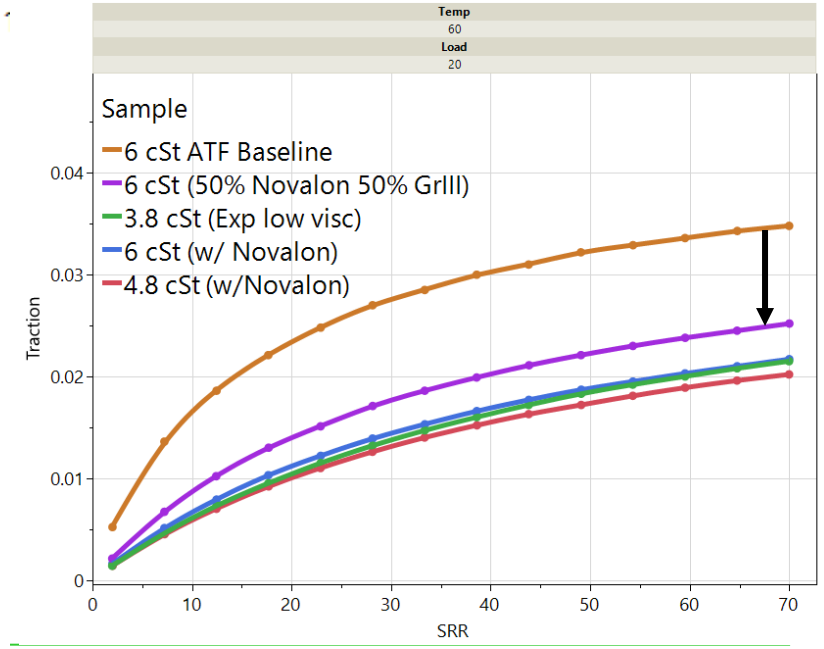
MODEL 3 DRIVE UNIT EFFICENCY BENEFIT 50% NOVALON : 50% GRP III

ΔEfficiency of 6 cSt w/ 50% Grp III: 50% Novalon over 6 cSt Baseline (all Grp III)

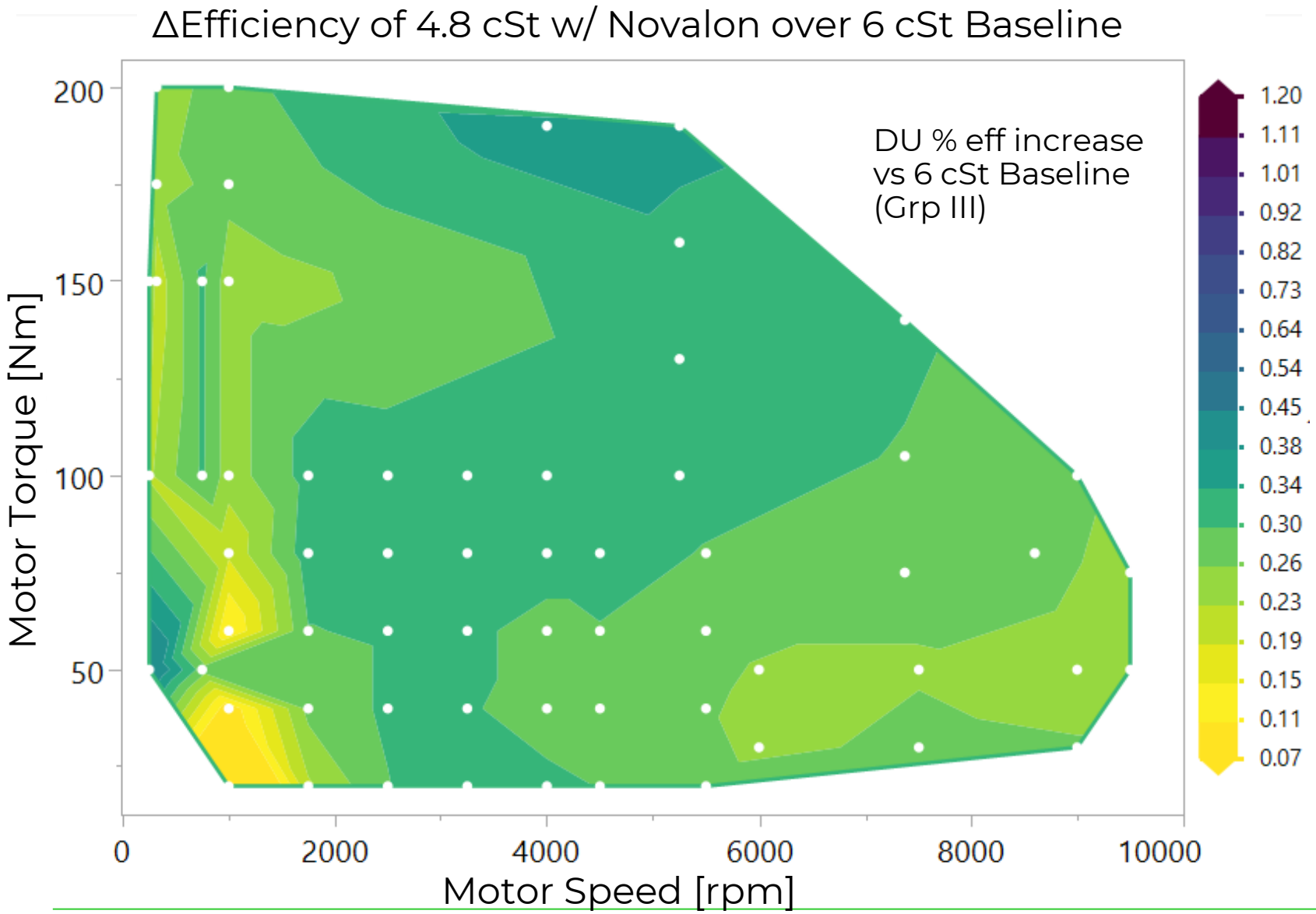


Inclusion of some Novalon with Grp III shows some small gains over Baseline

- Gains are smaller and mostly in lower speed regions



MODEL 3 DRIVE UNIT EFFICENCY BENEFIT FROM NOVALON IN A 4.8 CST EDF

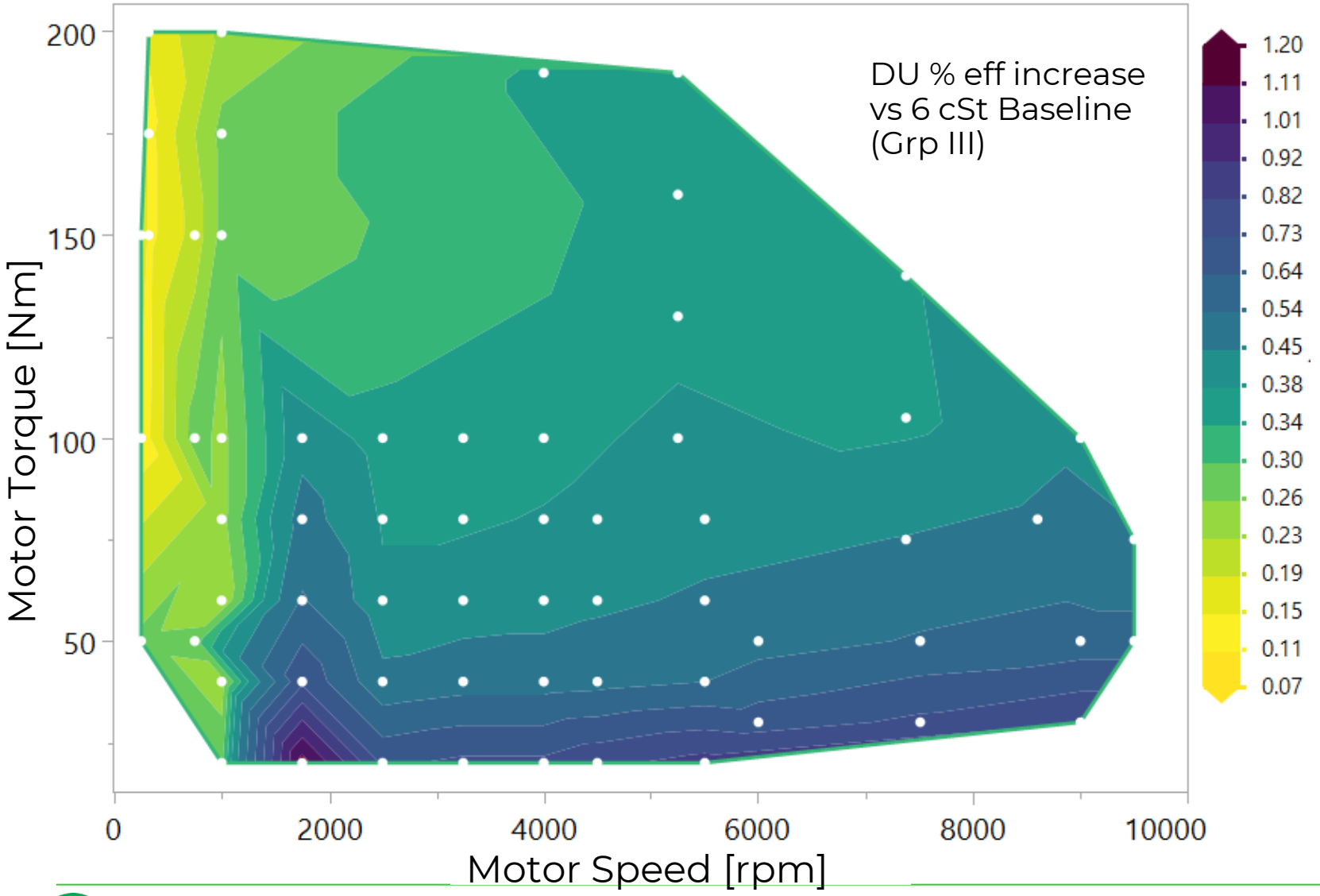


Reducing viscosity increases high speed efficiency gains

- 4.8 cSt formulation with Novalon^{tm} shows efficiency benefits over 6 cSt Baseline
- Lower viscosity allows for higher efficiency gains at higher motor speeds.
- Low motor speed improvements from Novalon^{tm} and additive combination are still present,

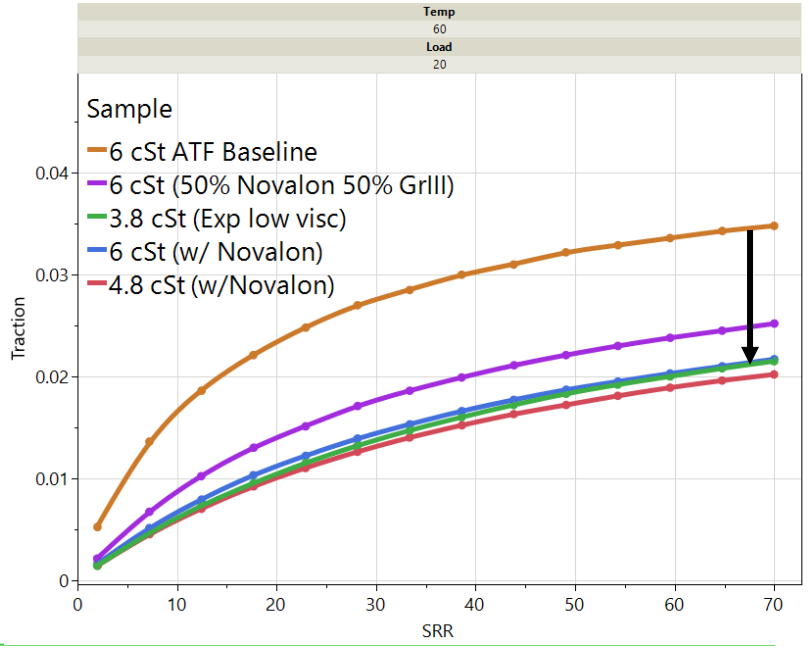
MODEL 3 DRIVE UNIT EFFICENCY BENEFIT FROM EXP LOW VIS IN A 3.8 CST EDF

ΔEfficiency of 3.8 cSt w/ Novvi Exp Low Vis over 6 cSt Baseline



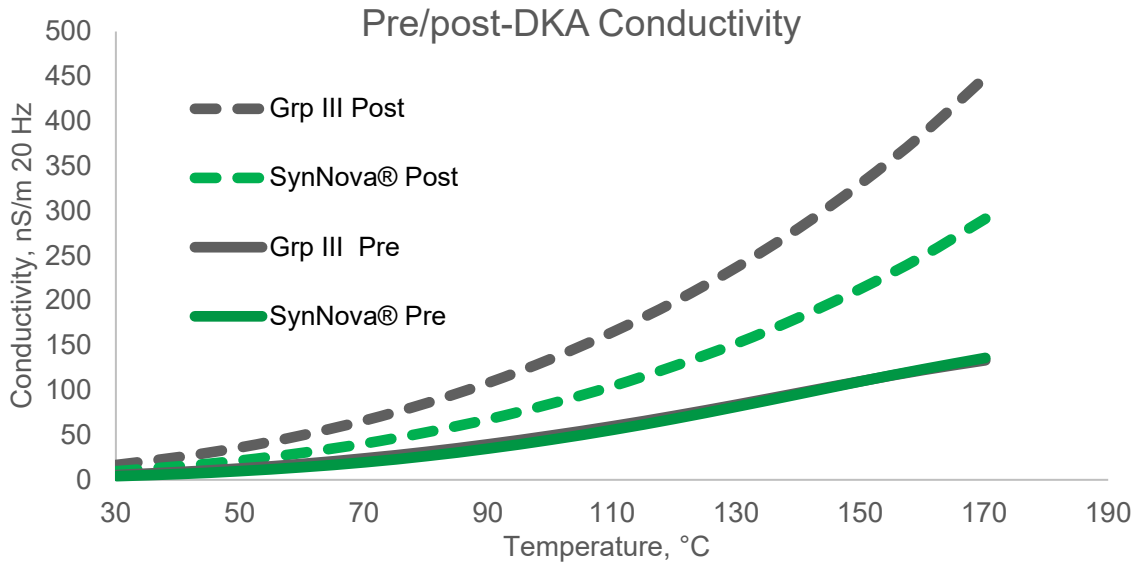
Further reducing viscosity increases high speed efficiency gains

- High speed efficiency gains are increased due to reduced churning losses and low traction



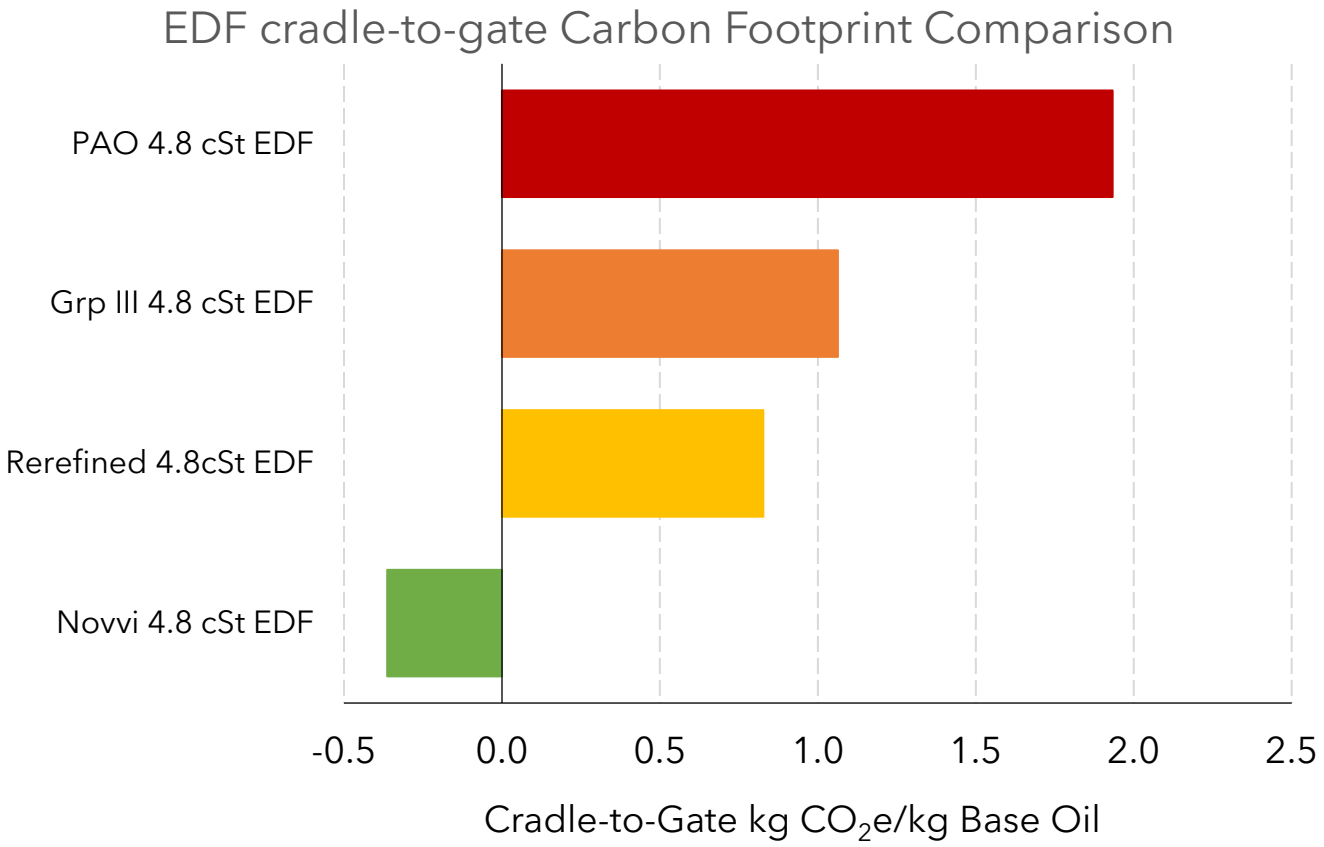
FINISHED FLUID FORMULATION: SYNERGY BETWEEN THE ADDITIVE & BASE OIL

Test	Group III 4.0 cSt	Group III 5.9 cSt	Novvi EDF 4.8 cSt	Novvi EDF 5.9 cSt
FZG A10/16.6R/90; FLS	7	9	9	9
FZG low speed gear wear (Verschleiss 120h)	23 mg	11mg	29 mg	7 mg



- The balance between the Additive & Base Oil provideS robust properties without compromise
  - The Additive is formulated to make the base oil technology and the viscometrics possible
  - Excellent wear and scuffing resistance
  - Superior and robust electrical properties

NOVVI'S BASE OILS ENABLE NEGATIVE CFP FORMULATIONS



- Novvi's base oils have -0.51 KgCO2e/kg cradle-to-cate carbon footprint (CFP)
- The renewable carbon in Novvi's base oil enables an EDF with a negative cradle-to-gate CFP and > 1 kgCO_2e/kg delta over conventional oils.
  - Grp IV EDFS - 2.3 kgCO_2e/kg
  - Grp III EDFs - 1.4 kgCO_2e/kg
  - Rerefined EDFs – 1.2 kgCO_2e/kg

Petroleum derived base stock Cradle-to-Gate analysis; obtained from peer reviewed publications:
Girotti et al, 2011, Fehrenbach, Ifeu 2005

LCA for Novvi's SynNova base oils have been validated and certified to meet PAS2050 and ISO14040,/ISO14044 standards

SUMMARY

Base Oil Structure and Viscosity significantly impact drive unit efficiency through:

- Reduced coefficient of friction
- Improved Thermal conductivity & Heat capacity
- Increased Oxidative stability for fill for life peformance

Synergy between the base oil structure, viscosity, and the additive systems are necessary to provide efficiency benefits with no compromise in other key performance areas such as:

- Wear performance
- Electrical properties
- Oxidative stability

Sustainability and performance are tied together.

- Novvi technology enables a negative carbon footprint cradle-to-gate EDF.
- Improved energy efficiency also improves the OEM and end consumer carbon footprint (gate-to-grave GHG impact) while driving value through improved range.

ACKNOWLEDGMENTS

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Thank You!

For further questions and discussion, please feel free to contact the presenters:

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