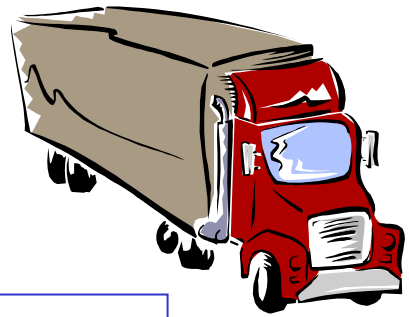
# Alternative Fuels- Dimethyl Ether Rheology and Materials Studies

Without sacrificing

Performance

Cost



Engine Compatibility

Ease of Use

**Goal:** Quantify and characterize fuel system interactions
and
elastomer compatibility with dimethyl ether

PennState

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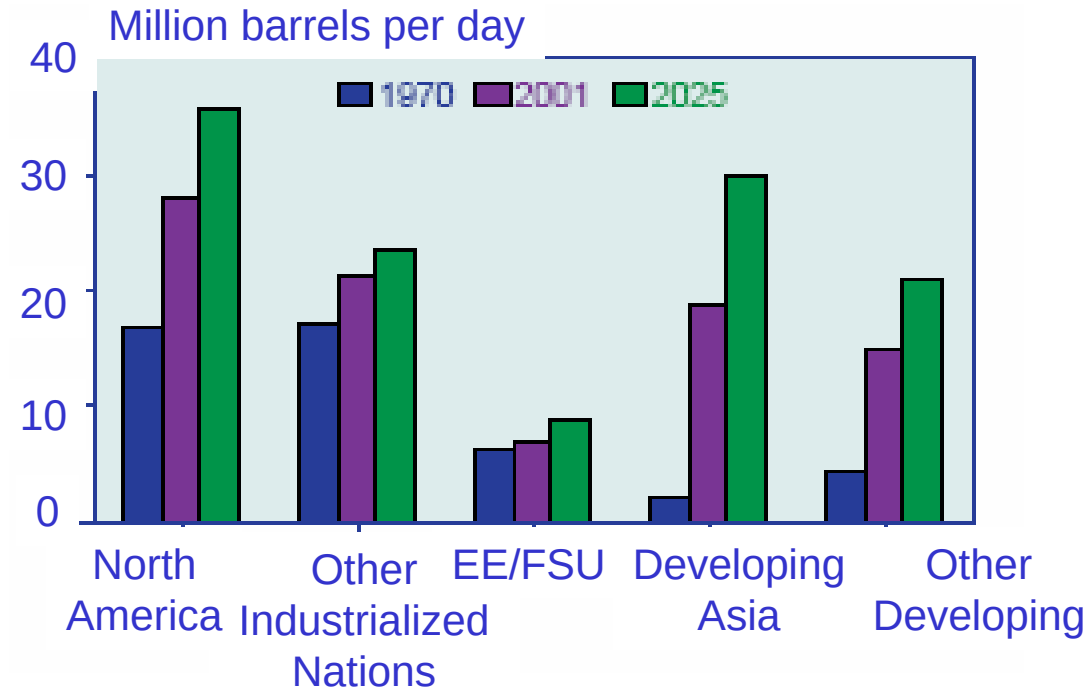
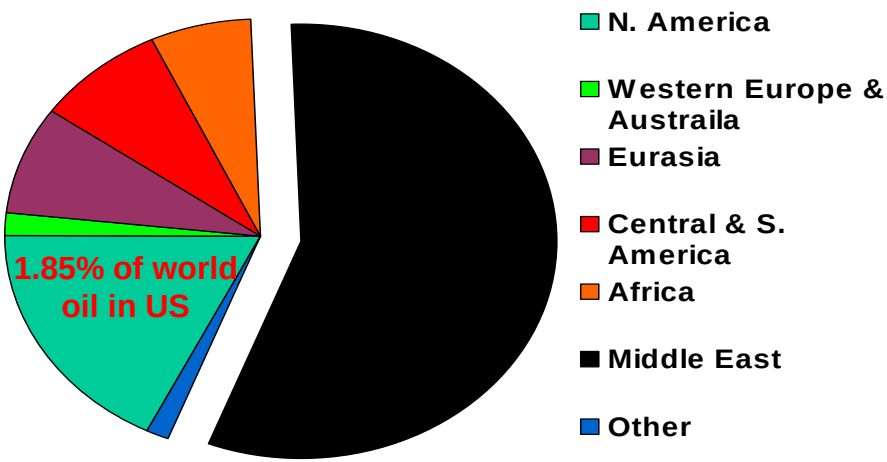
# Petroleum Outlook

How much petroleum is the world consuming?
According to DOE…



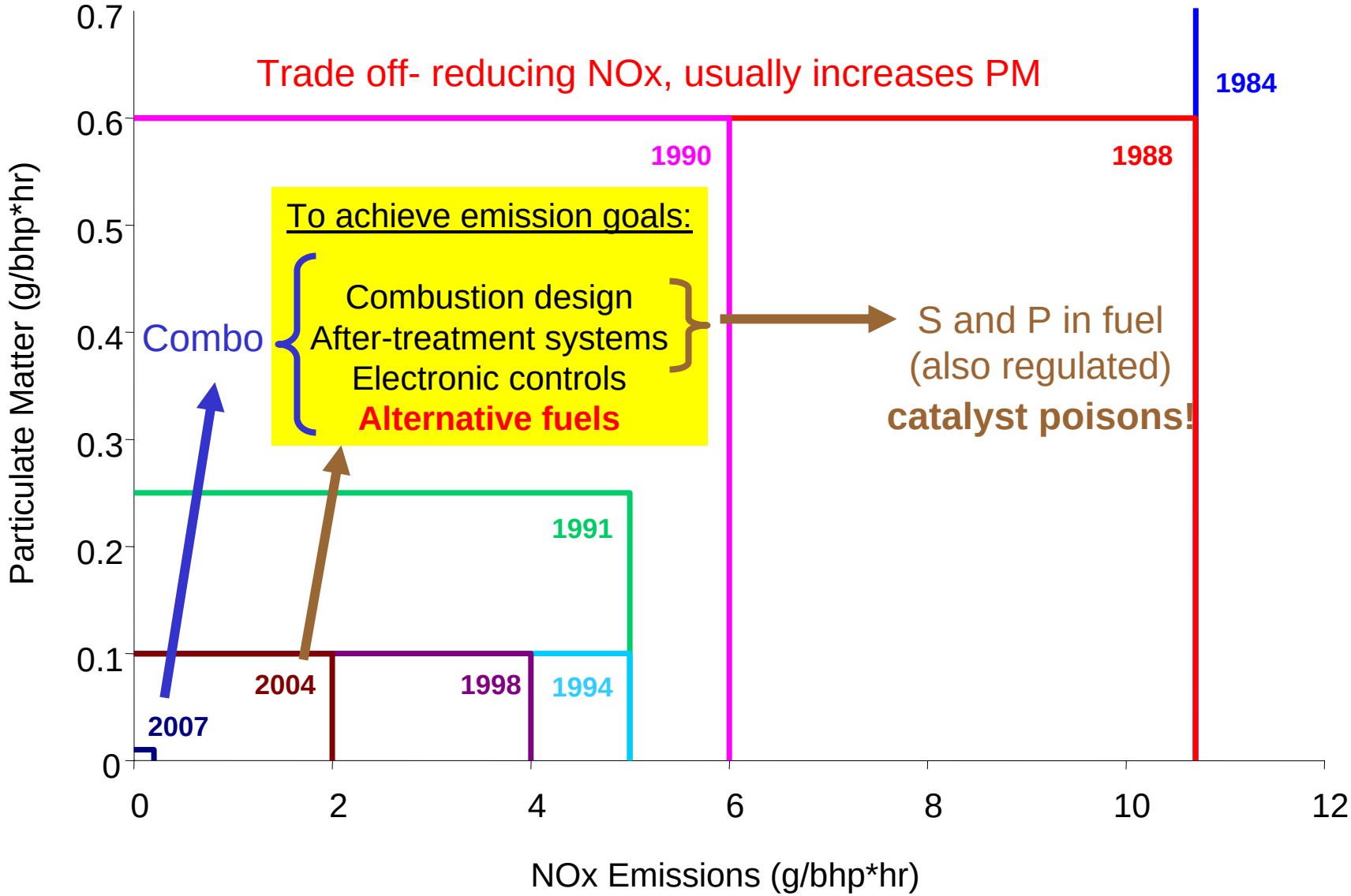

Developing countries will require massive resources

Where is the world's oil located?
(proven reserves)




US has extremely limited proven oil reserves, imports

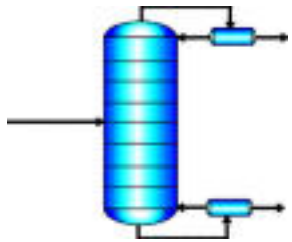
# US Diesel Emissions Regulations



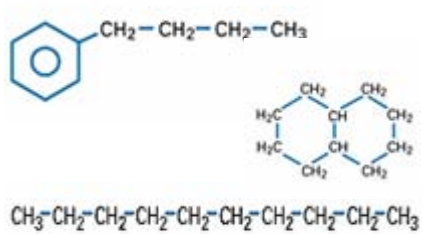
# Fuel Studies at PSU

## Diesel Fuels

Petroleum cut boiling
~282-338°C
LSDF 325 ppm S
ULSDF < 15 ppm S



Distillation



Hydrocarbon mixture

Soybeans

+ ROH $\xrightarrow{\text{catalyst}}$

## Biodiesel Fuels

Blends of methyl esters made from vegetable oils- renewable!
No sulfur, phosphorus content

## Dimethyl Ether

Converted biomass- renewable!
Zero emission fuel, gas at STP

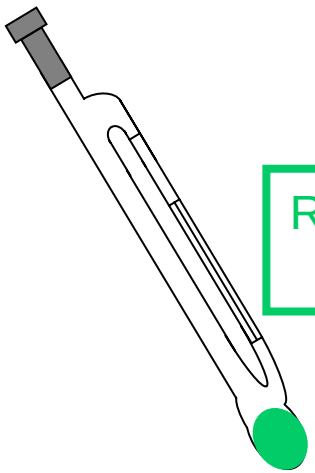
Hydrocarbon → Syngas → DME

# DME Areas Investigated

**Fuel Injector Lubrication**

Mimic fuel injector response

**Viscosity Improvement**



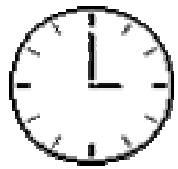
Raise to ASTM lower limit (DME)

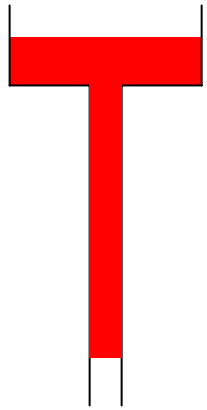
**Elastomer Durability**

How alternative fuels effect physical properties

# Viscometry

**Principle:** Time for a certain volume of liquid to move through a calibrated capillary





Pressurizable design

Small capillary for enhanced accuracy

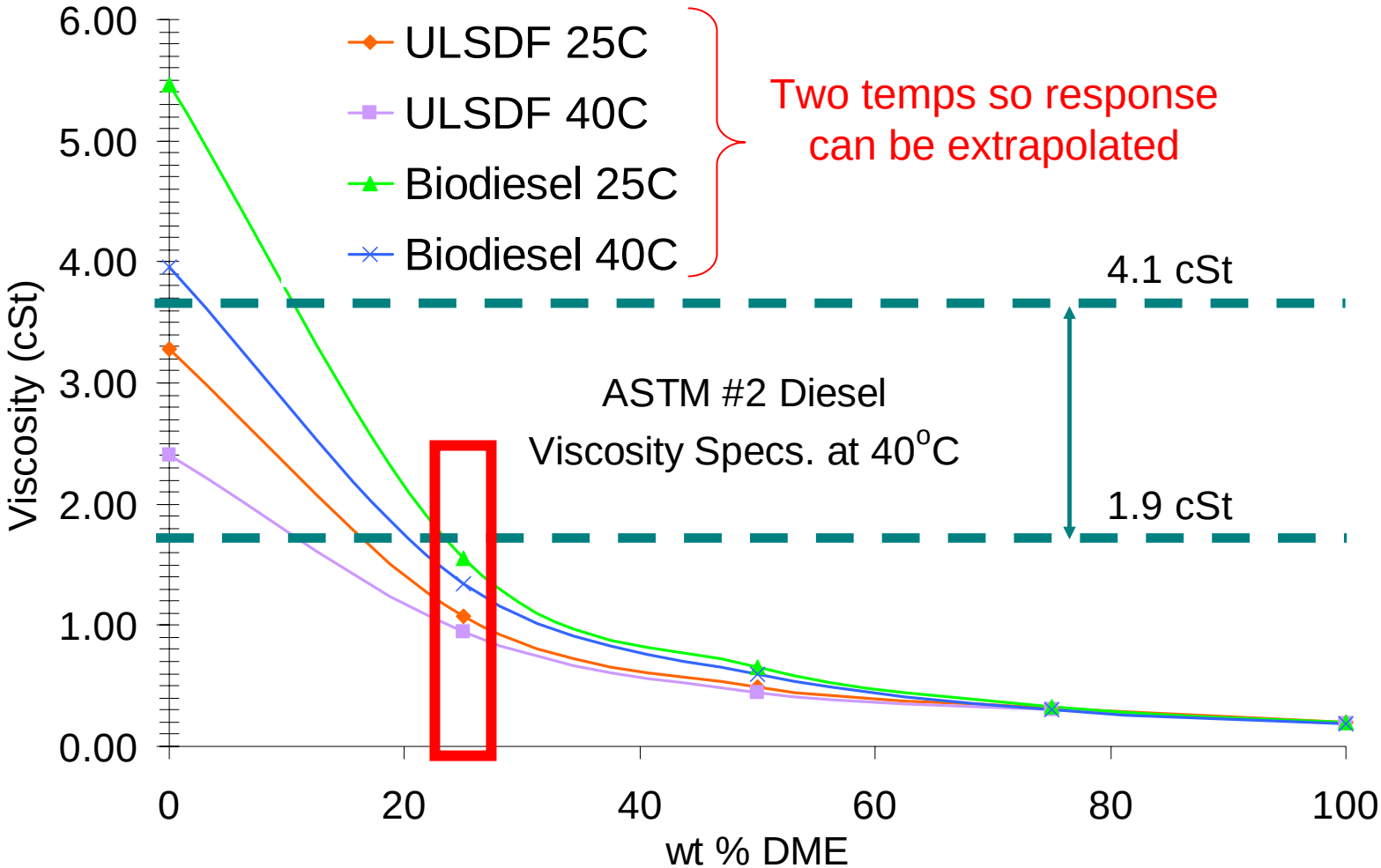
Adaptable Swagelock® fitting at fill port

$$\upsilon = \frac{10^6 \pi g D^4 H t}{128 V L}$$

**Test Matrix**

Typical viscosity improving additives
Environmentally friendly additives
Blends of DME and diesel- with and without additives
Blends of DME and biodiesel- with and without additives

# Viscometer Data




Dramatic decrease in viscosity with addition of DME in small quantities

# Additives Used

Traditional

**Polymethacrylate**- Long chain ester (OFM, VI)

**Olefin Copolymer**- Ethylene/propylene non-conjugated diene (VI)

**Alcohol**- Ethoxylated long chains (OFM)

Synthetic

**Poly-a-olefin**- PAO-40 “40” refers to kinematic viscosity at 100 $^{o}$C (VI)

Environmentally Friendly

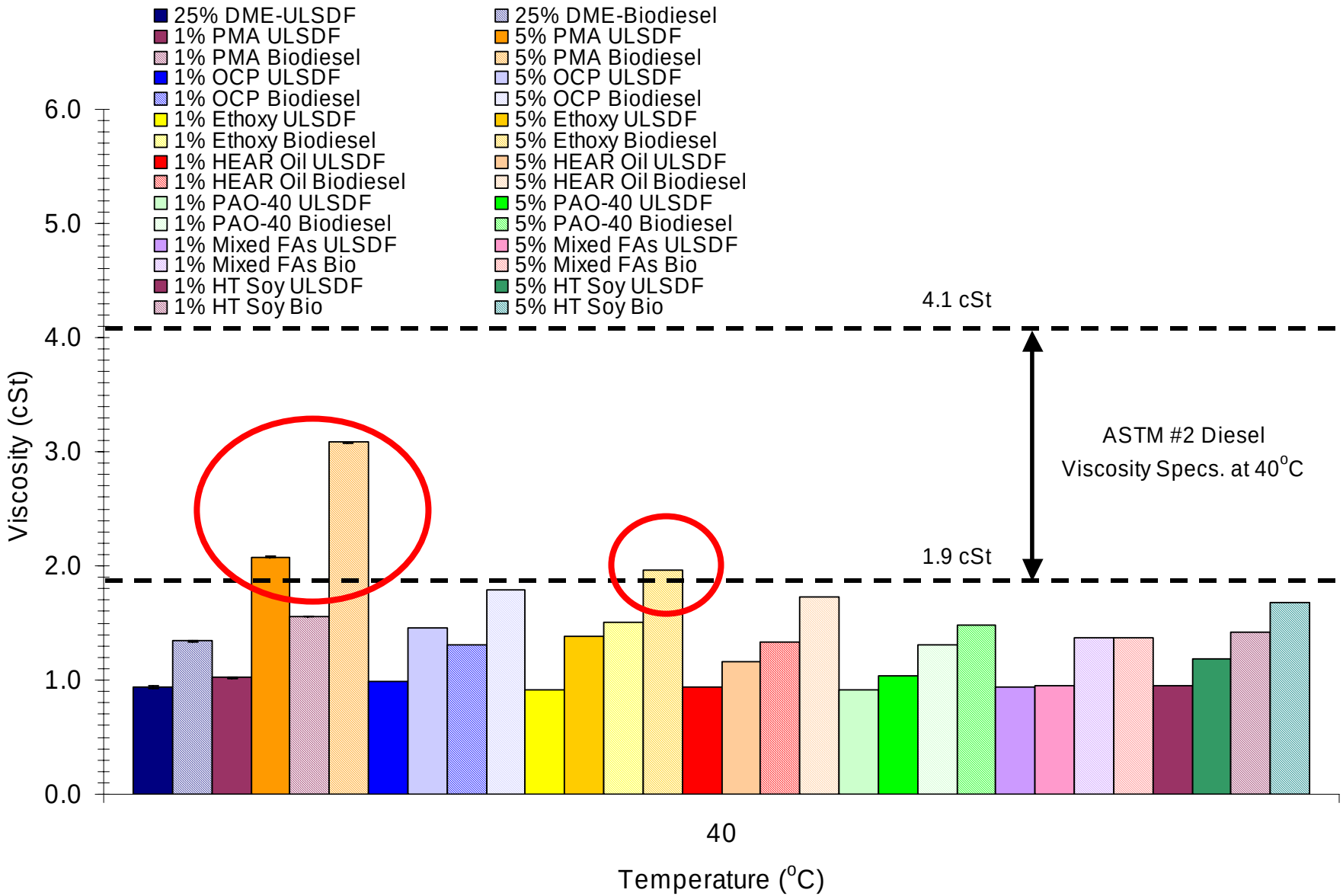
**Vegetable Oil**- Heat modified (polymerized) soybean oil (OFM)

**Vegetable Oil**- Mixed fatty acids (OFM, VI)

**Vegetable Oil**- Oleic acid alternative (OFM, VI)

# Additive Effect

1 and 5 wt % concentrations tested in 25 wt % DME



# Material Compatibility

## Fuel-Elastomer Interaction

Throughout the engine elastomers such as gaskets and o-rings provide proper seals and maintain the appropriate fuel environment

What happens with Dimethyl Ether?

→ Severe breakdown
Loss of elasticity
Swelling

Result: Seal failure during operation and/or storage

Approach: Soak o-rings in DME and test physical properties (mass, volume, diameter) and elastic response (tensile properties). Deduce trend and formulate a failure mechanism.

# Elastomer Durability

Chosen materials represent major types commercially available:

Buna-n

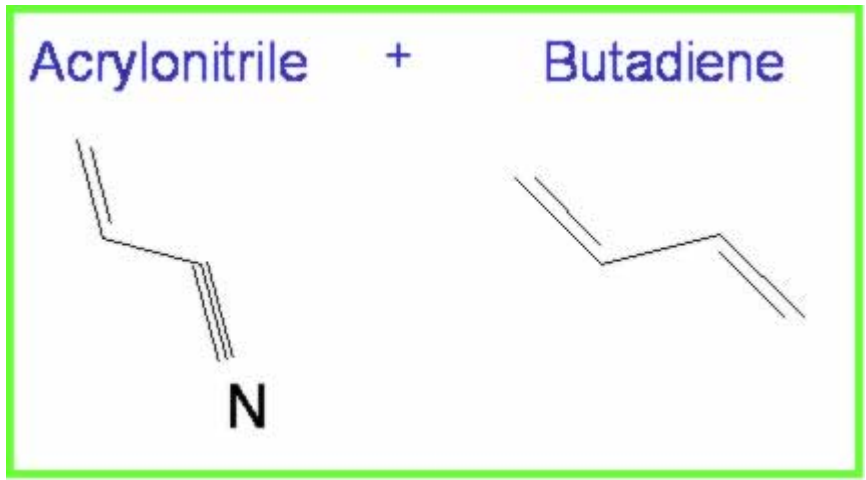
Silicon

Viton

Polyurethane

Teflon

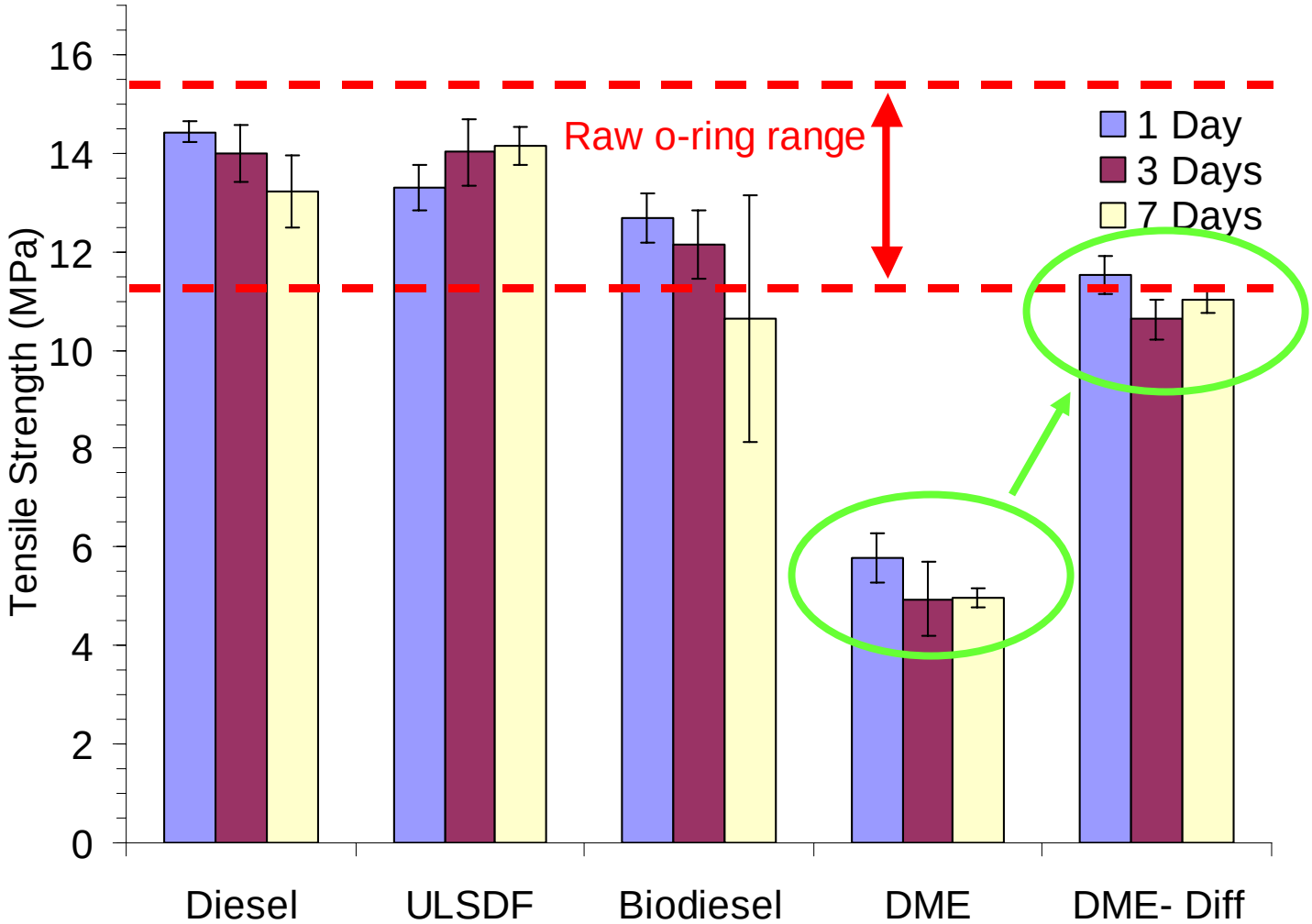
Kalrez (fluoro-polymer)




Expensive specialty polymer with high chemical resistance

DME tested 1) right out of pressure vessel and 2) after diffusion of DME out of o-ring (temporary versus permanent damage)

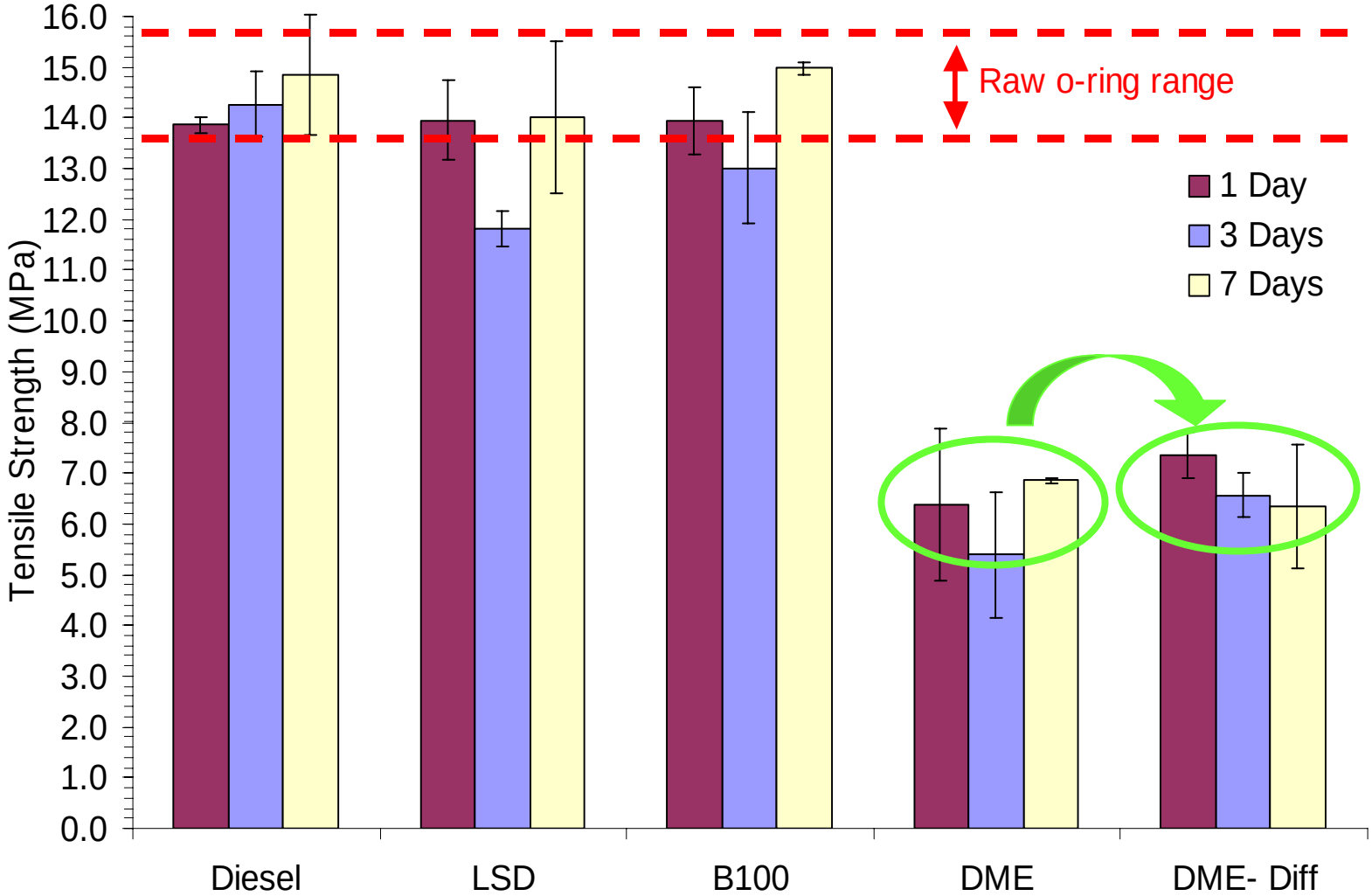
# Buna-N Fuel Response




**Strength loss is temporary and likely due to partial solvency of fuel in elastomer**

**Extended exposure leads to performance compromise in DME**

# Kalrez Fuel Response




**Strength loss is permanent and likely due to rupture of crosslinking**

**Extended exposure leads to deterioration in DME**

# Fuel Injector Wear

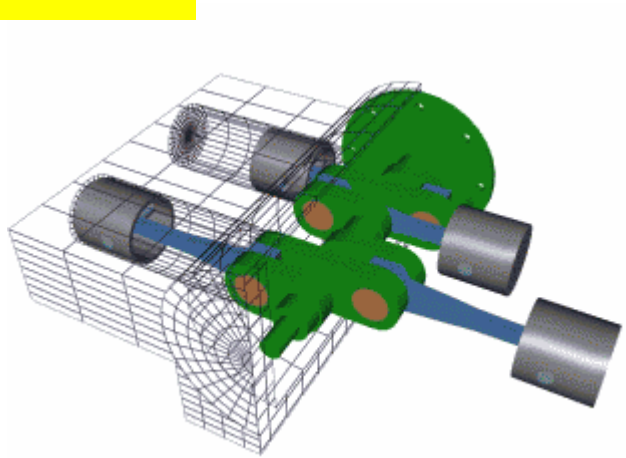
**Bench Testing**

**Goal:** Faster, less expensive test that accurately predicts fuel injector behavior

Modified Cameron-Plint wear tester

Pressurizable housing

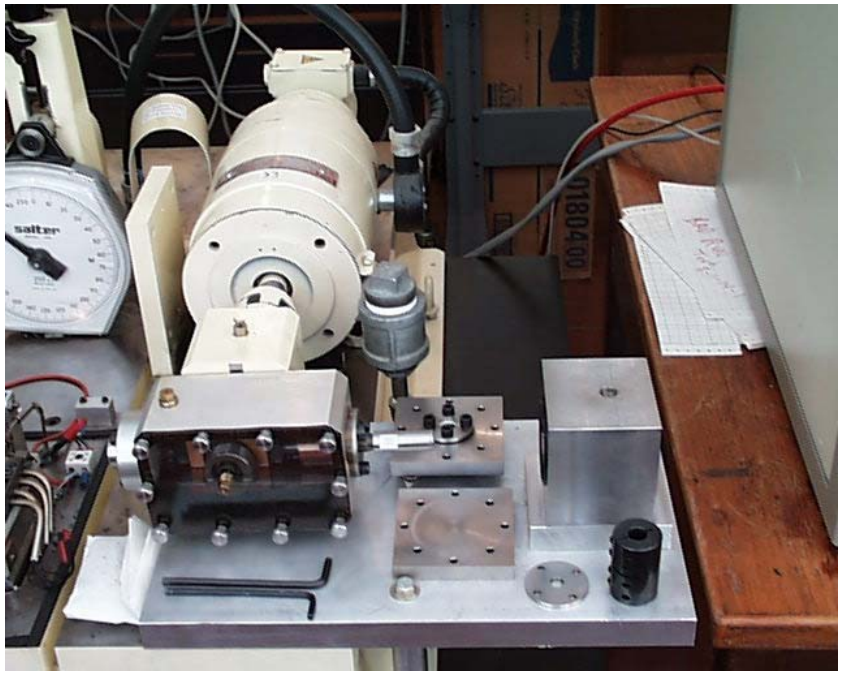
Utilizes parts duplicating actual injector parts:
- Same geometry as diesel injector
- Same surface roughness and materials
- Operates at typical or higher frequency



Total costs per test: ~$250 vs. $5000 for full engine test
Total operational time: 3 hrs. vs. weeks for engine test

→ Significant savings!

# Cameron-Plint Device



**Modified Cameron-Plint**

Matching outer cylinder per pin

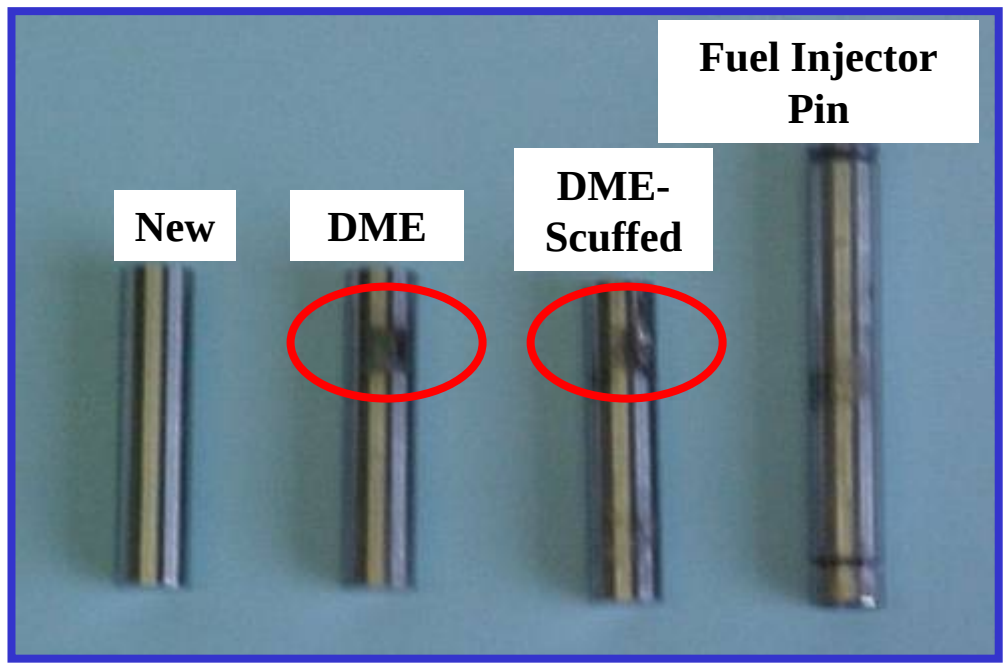
Capable of 2 tests /cylinder
1 per pin

Variable speed motor, 0-50 Hz

Fully simulates injector motion

Pin travel distance: 1mm

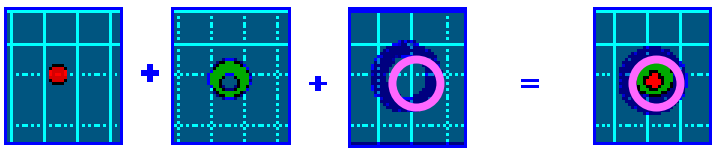
**Test Pins**



# Wear Scar Mapping

Wave/light interference generates a horizontal light plane which is used as a surface probe

Successive intersections between the probe plane and the sample are the relief level curves



MicroXAM™ Surface Mapping Microscope

| | |
|---|---|
| Pros: | Fast image acquisition<br>Easy to use<br>Robust technique |

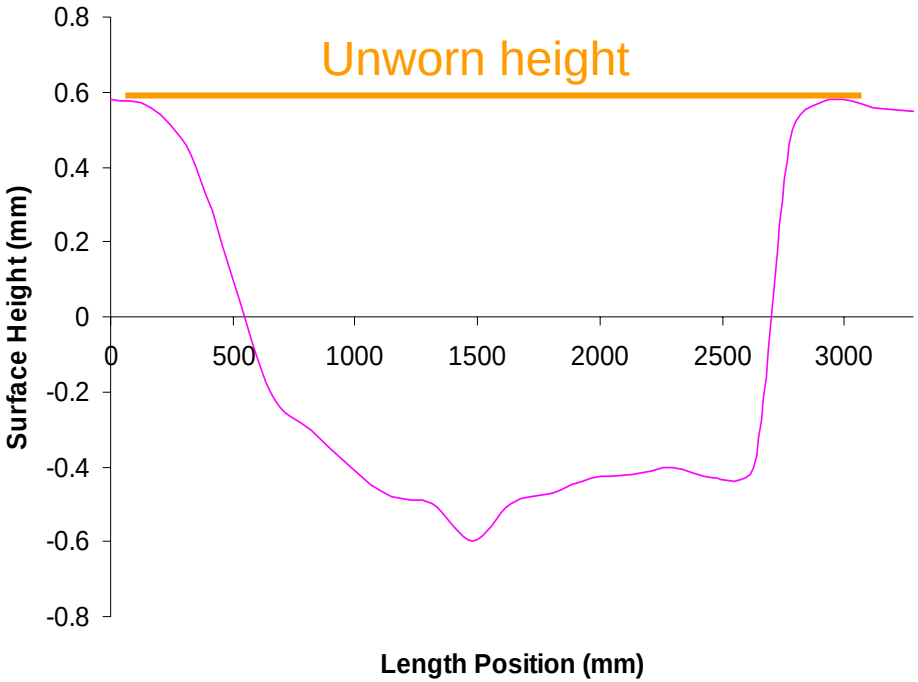
| | |
|---|---|
| Cons: | Res. limit ½ wavelength of light source<br>Curvature problematic |

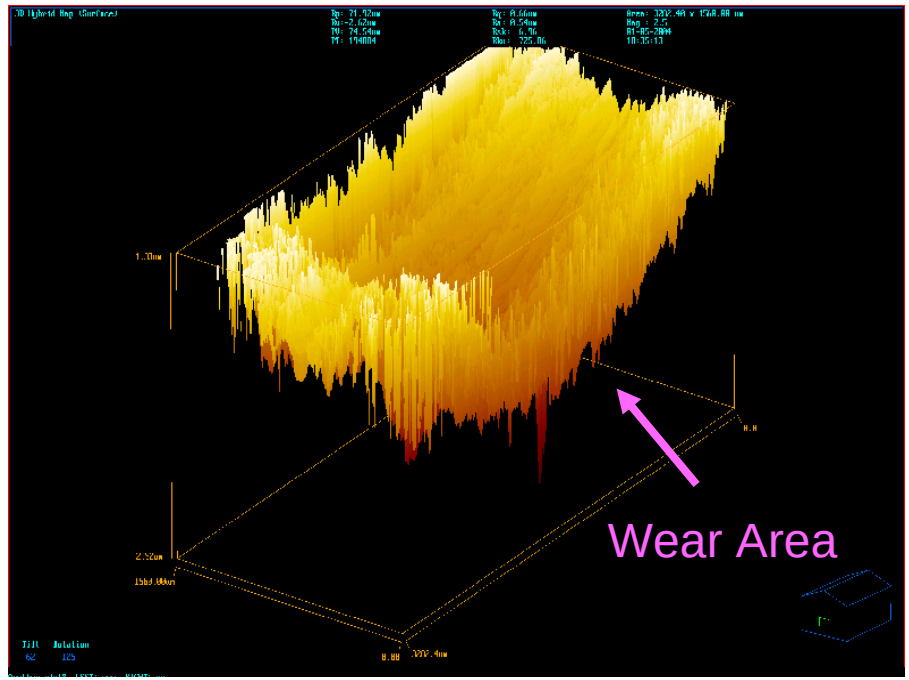
# Wear Scar Examples

75 wt % DME/25 wt % ULSDF

Scar flattened, curvature removed

Depth of scar $\alpha$ severity of wear

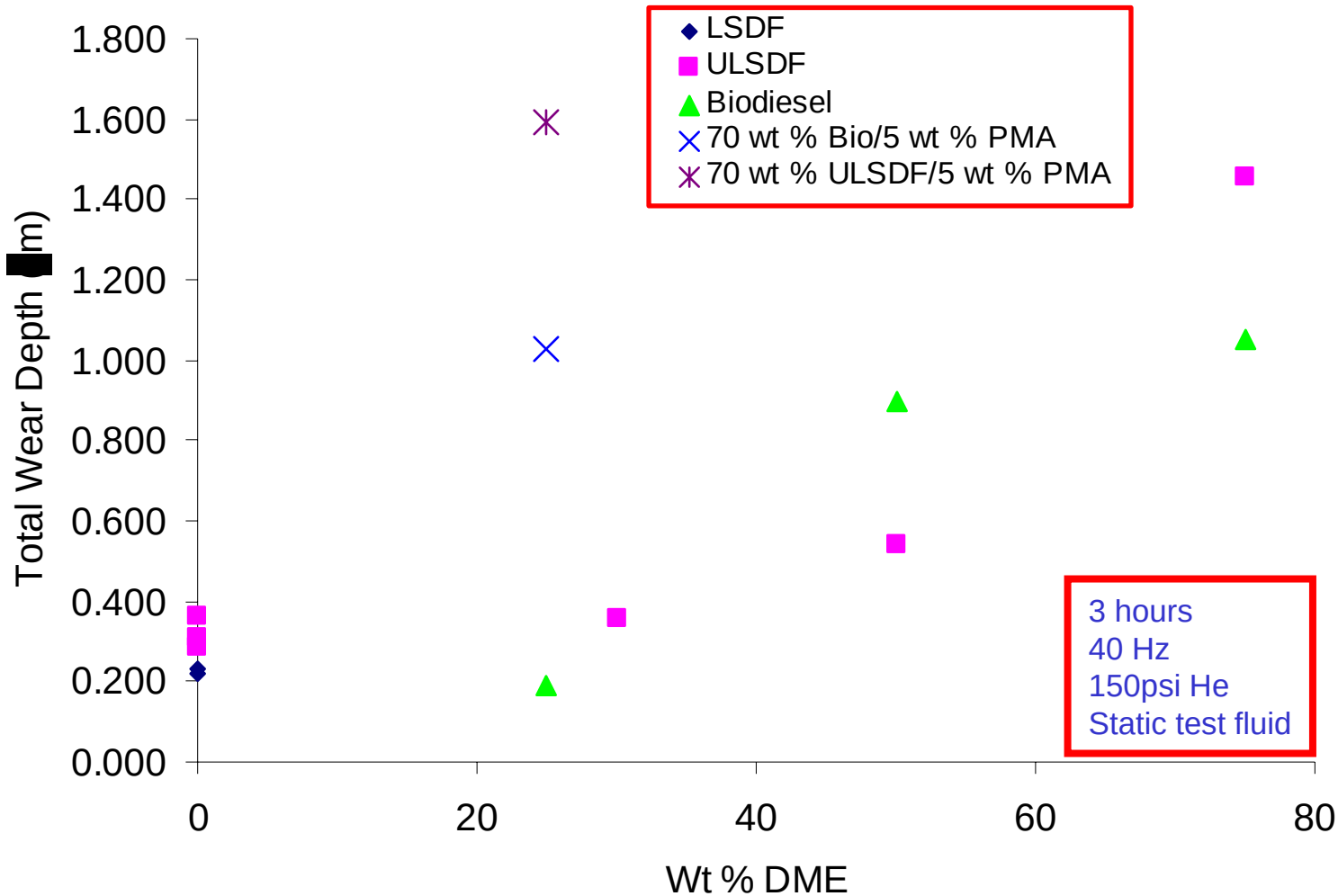



Data confirms trend of incr. wear with incr. [DME]

Discrimination between ULSDF and biodiesel blends possible

# Cameron-Plint Data




Increasing wear scar depth with increasing [DME]

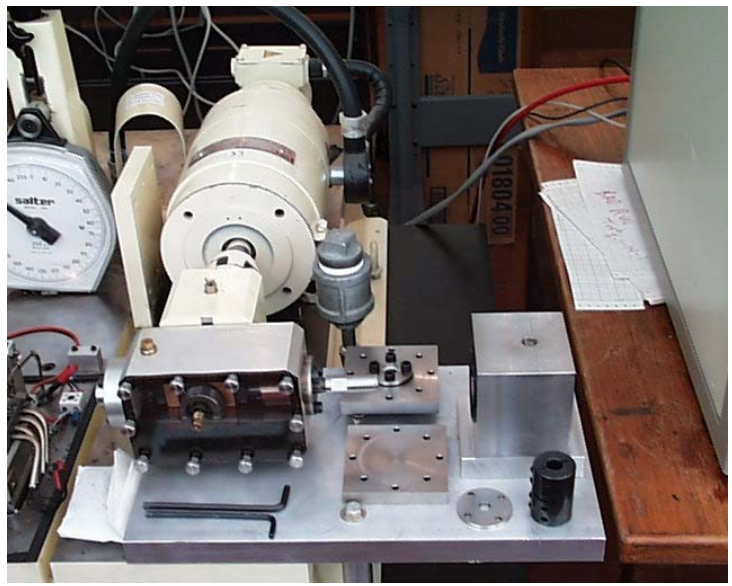
Additives caused deeper scar: cycled fuel mixture=shearing of additives
chemical corrosion; 3 body wear

# Summary

Viscosity

Material Compatibility

Alternative Diesel Fuel Understanding



Fuel Injector Wear

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THANKS - CAPTAIN JOHN
CAPTAIN – Is Port Left or Right?