Storage, Handling and Combustion of a Novel Heating Fuel: EL

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Presented by Ryan Kerr

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NORA

- NORA is the National Oilheat Research Alliance - a congressionally authorized organization that has, as one of its mission's, biofuel conversion
- NORA frequently gets new candidate biofuels for evaluation
- In this presentation we discuss our process for evaluating new candidate fuels but are focused on Ethyl Levulinate (EL) because it is close to commercialization and because of the interest in the fuel particularly in the state of Maine

Studying a New Fuel for Field Usage

How will a new fuel function in an existing residential and commercial liquid heating system?

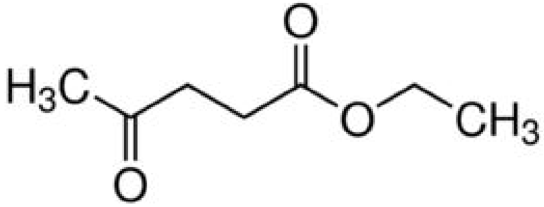
What parts of the system are compatible and what needs to be changed?

Areas to be evaluated:

- Blending with existing fuels
- Material compatibility
- Combustion testing
- Storage stability

What is Ethyl Levulinate (EL)?

- Renewable biofuel derived from cellulosic material
- GREET model shows EL could reduce GHG emissions between 110 and 120 percent when compared to petroleum No. 2 oil
- Biofine Developments Northeast (BDNE) is currently working on a 3 million gallon per year production plant in Lincoln, Maine.



Ethyl Levulinate

EL Production - The Biofine Process

A proprietary biomass refining technique that enables the production of levulinic acid from a variety of cellulosic wastes.

Chemical Intermediate levulinic acid via a fast continuous dilute acid hydrolysis reaction.

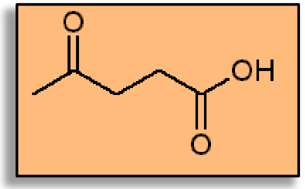
Compact, chemical conversion, carbon negative, and energy self-sufficient.

Demonstration Plant at the at University of Maine Orono.

First Stage "Plug Flow" Reactor

Fast Reaction (Seconds)

Slower Reaction (Minutes)



Cellulose → Sugars → Intermediates I → HMF → Intermediates II → Levulinic Acid (50 wt %)

EL Properties

		No. 2 heating oil	Biodiesel (FAME)	Ethyl Levulinate (EL) $C_7H_{12}O_3$
Composition	C wt%	86	75.5	58.3
	H wt%	14	12.6	8.3
	O wt%	0	11.9	33.3
Density	g/cm^3	0.851	0.884	1.02
Higher Heating Value	MJ/kg	45.55	40.73	26.29
	MJ/L	38.74	36.00	26.82
Flash Point	°C	38 min	93 min	91
Viscosity	mm^2/s @ 40°C	1.9 – 4.1	1.9-6.0	1.5
Cloud Point	°C	-12 – -6	-6 – 14	< -50

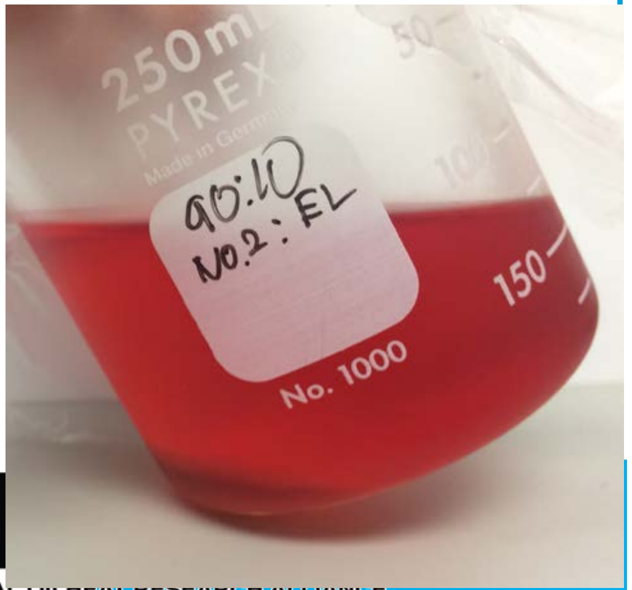
Blending EL and No. 2 oil

- No. 2 oil and EL separate at room temperature in blends higher than 20%

70/30 No. 2 oil:EL
24°C

- Blends of 20% and less will separate at colder temperatures
  - 80/20 No.2 oil:EL separates at 13°C
  - 90/10 No.2:oil:EL separates at -9°C

90/10 No. 2 oil:EL
Separated at -9°C

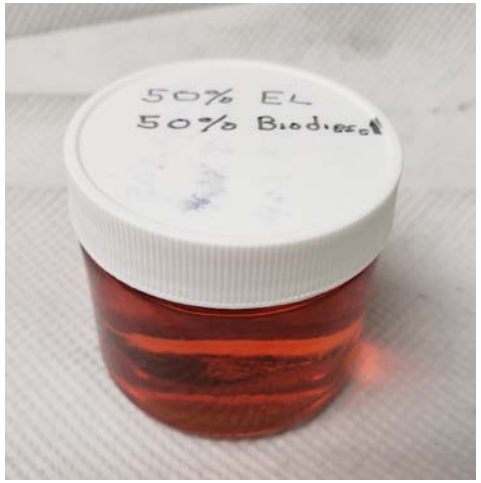


Blending EL and Biodiesel

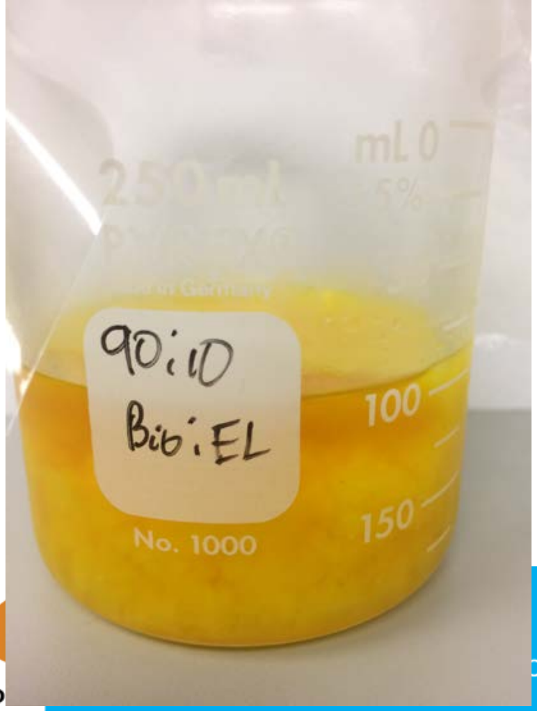
- EL and biodiesel can blend at any level with no separation issues
- Cloud point of blends is governed by the biodiesel cloud point

Fuel Blend	Cloud Point (°C)
B100	1
95/5 Bio:EL	-1
90/10 Bio:EL	-2
80/20 Bio:EL	-2
50/50 Bio:EL	-3

50/50 Bio:EL,
no separation



90/10 Biodiesel:EL
-6°C



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EL Blend Test Matrix

Sample	Kerosene (%)	Biodiesel (%)	EL (%)	No. 2 oil (%)	Renewable Diesel (%)	Clouding Temperature (°C)
1	100	0	0	0	0	<-20
2	0	0	0	100	0	-17
3	50	0	0	50	0	<-20
4	0	50	50	0	0	-6
5	33.3	33.3	33.3	0	0	-17
6	16.67	33.3	33.3	16.67	0	-15
7	20	40	40	0	0	-17
8	50	50	0	0	0	-17
9	0	33.3	33.3	0	33.3	-15
10	0	20	0	80	0	-17
11	40	20	0	40	0	<-20
12	40	35	25	0	0	-20
13	42	42	16	0	0	<-20

40/35/25 Kero:Bio:EL
at -17°C

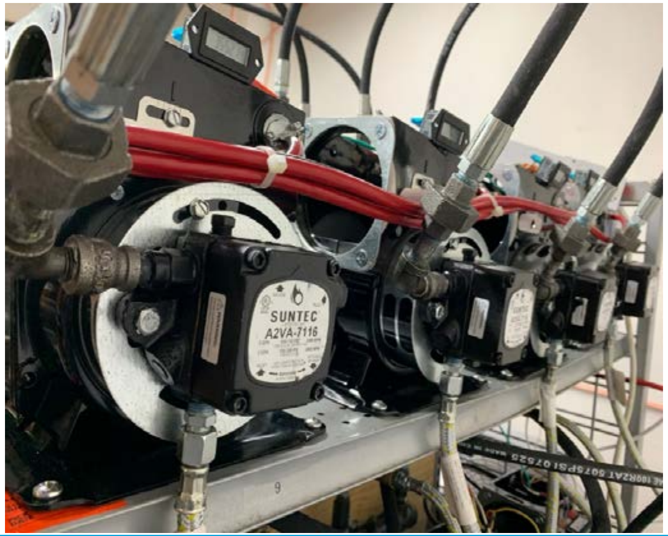
Elastomers

- EL 100 not compatible with Nitrile and Viton elastomers commonly used in fuel oil applications;
- Acceptable with Silicon, Teflon, Alfas;
- For small burners, use of carbon face shaft seals found to be acceptable;
- For pump lip seals a Teflon/Graphite composite seal has been developed and found to be acceptable in early testing;
- For combustion testing in residential and commercial applications all components need to be changes or have modified seals inserted.

Soft Materials

Fuel Pumps

- Positive displacement – gear sets
- Provide suction lift and pressure for atomization
- Internal pressure regulator with pressure control valve bypass either back to tank ("two pipe") or internally back to inlet port ("one pipe")
- Various bypass/shutoff arrangements in use to provide very clean startup and shutdowns
- In residential use ~ 10,000 cycles per year.



Fire Safety Valves

- Designed to stop flow of oil from the fuel tank to the burner in the case of a fire
- Most common safety valves in the liquid heating industry are fusible head fire vavles
- Soft materials in included are typically Nitrile or Viton

EL Filter Compatibility

- See the effect of EL on a filter used in the field
- Foam (cellulose acetate) filter submerged in 100% EL

Start of Test (0 min)

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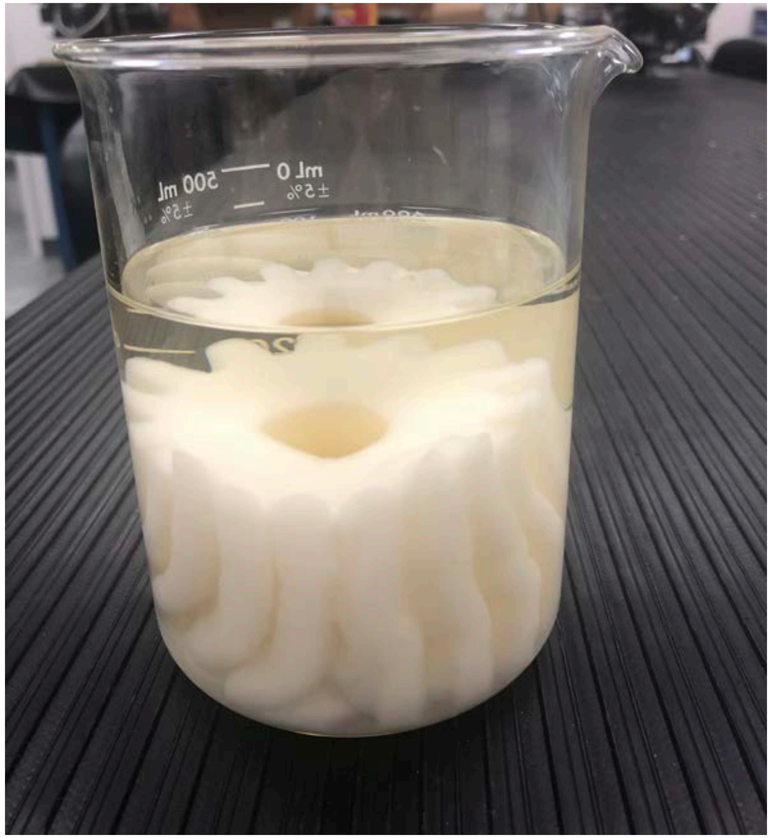
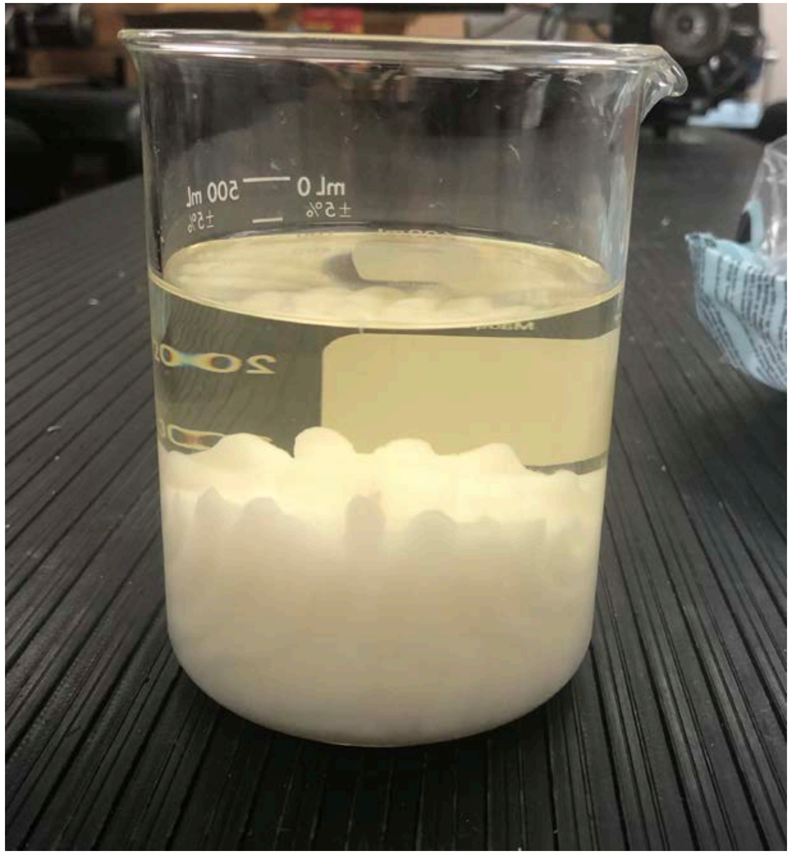
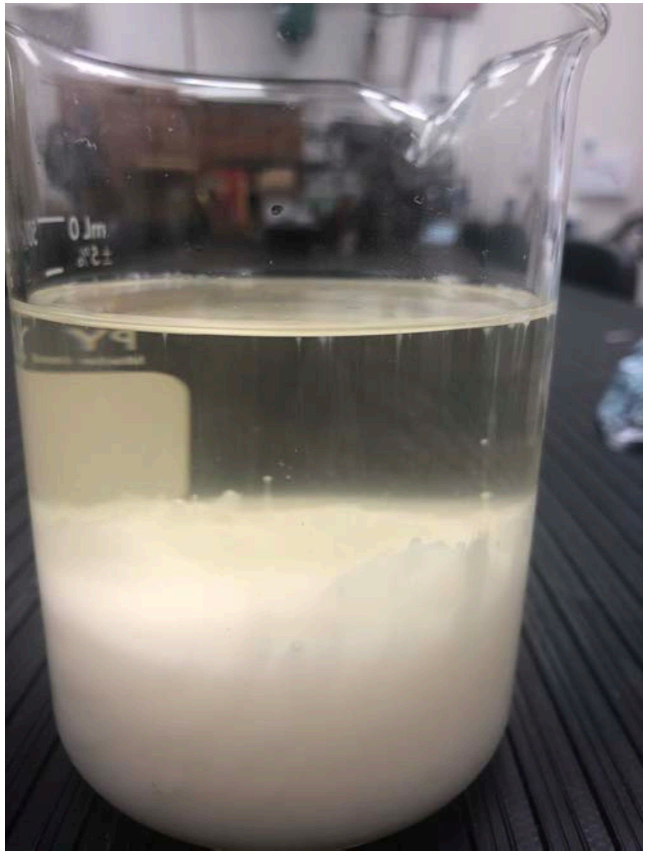
EL Foam Filter Compatibility (cont)



20 minutes



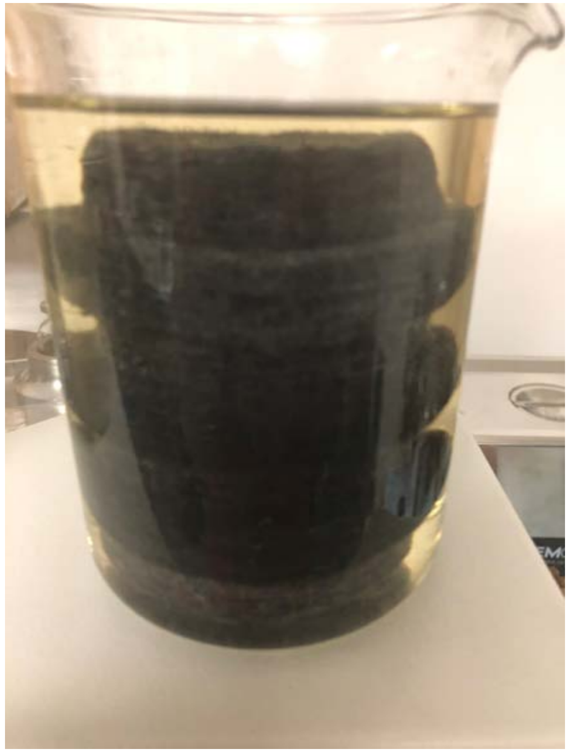
30 minutes



60 minutes

EL Filters

- Filters also tested in EL which showed no effect:



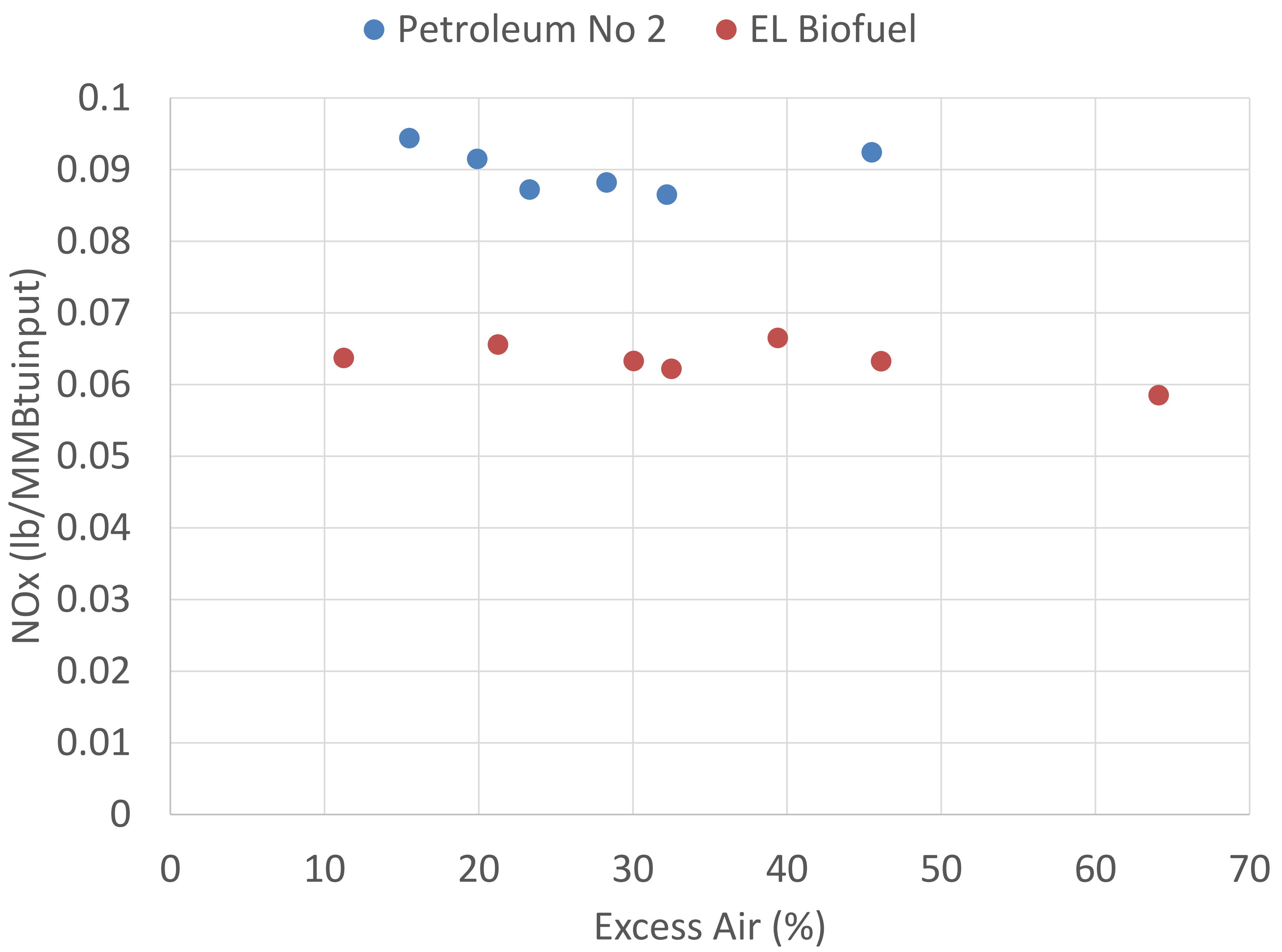
Felt Filter

Spin-on Filter

Yarn Filter

EL Combustion: Commercial Scale

- Tests were conducted in a Weil-McLain 688 Cast Iron Section boiler configured with direct cold water at the boiler inlet
- Burner installed in the boiler for this test was a Model 601 CRD manufactured by Carlin Combustion Technologies
- Input rate: 410 kW



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Flame

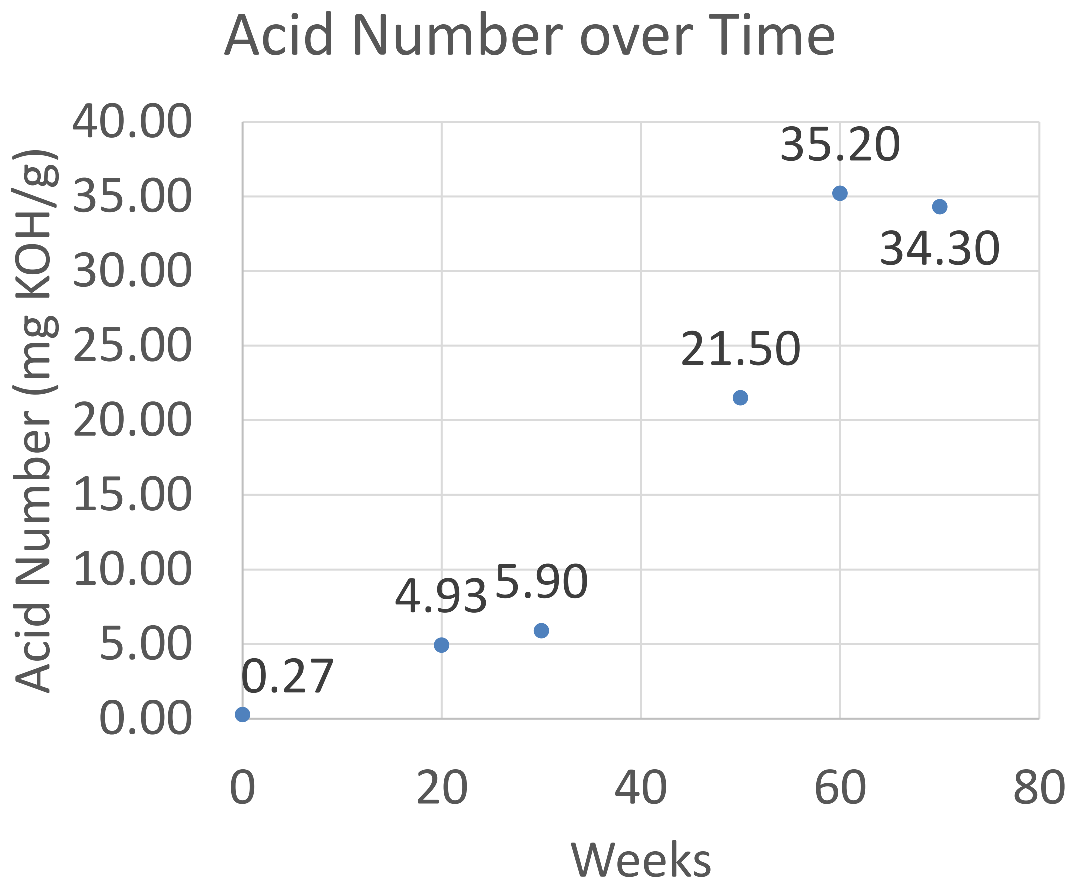
Petroleum No. 2

EL 100

Same excess air and input rate (1.5 MMBtu/hr)

Long Term Storage

- Degradation characteristics of EL still being studied
- Accelerated aging of EL was done by storing fuel at 43 °C (ASTM D4625)
- Main area of change was the acid number (ASTM D664) of the fuel

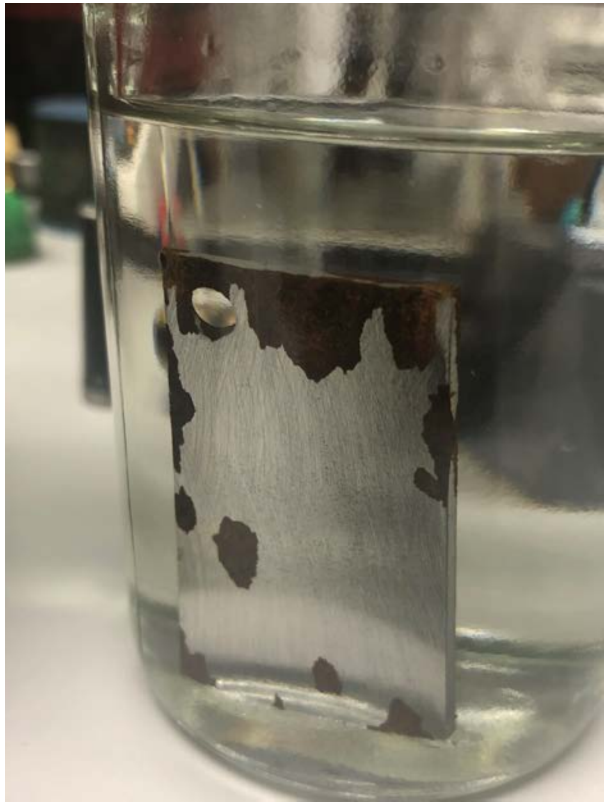


Increased Acids - Angelica Lactone

- Testing of EL batch produced to match pilot plant production showed higher than expected TAN
- TAN also increased rapidly in long term storage testing
- Issue attributed to a minor component of the fuel, Angelica Lactone (about 2%)
- Angelica Lactone reacted with water to form levulinic acid
- New distillation step added to production to eliminate impurity

EL and Water – Steel Corrosion

- EL has a saturation point of about 8.5% water
- Concern has been raised about what EL mixed with high amounts of water will do to the steel found through the industry
- EL with no water or low amounts of water (1%) have shown no issues
- EL with 8% water has shown buildup on the steel. Currently looking at the use of metal deactivators



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Draft ASTM Standard

- Established EL100 – ASTM Working Group
  - NORA, NREL, Beckett, Biofine, Sprague
- ASTM Group D-02
- Process Started – June 2023
- Developed Draft ASTM Specifications & Definition
- Finalize ASTM Definition - 2024

DRAFT – EL100 Specifications

Property	Test Method	Required Value
Density kg/m³	D4052	1000 to 1020
Flash Point °C	D93A	>80
Kinematic Viscosity at 40 °C	D445	
min		1.4
max		4.0
Water, percent by mass	D1364	<1.0
Acid Number mg KOH/g, max	D664	<0.5
Sulfur content ppm	D2622	<15
Cloud Point °C	D5773	<-15
Pour Point °C	D97	<-40
Electrical Conductivity pS/m	D2624	>2,000
Copper Strip Corrosion max	D130	No. 3
Steel Corrosion	D665	Pass
Lubricity HFRR @ 60 °C micron max	D6079/D7688	520

Conclusions

- EL's properties make it behave very differently in a heating oil system than standard petroleum No. 2 oil or other biofuels such as biodiesel.
- Changes need to be made throughout the heating system; EL would not be a drop in fuel.
- It can however burn well in existing boiler and furnace systems.
- The corrosion of steel when EL is mixed with water is a large concern that needs more investigation.

Questions?

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