

Hydropower Plant Equipment Specifications – Opportunities for Innovation and Plant Modernization

Synthetic Esters in Power Transformers for Hydropower Plant Modernizations to Improve Fire-Safety, Reliability and Mitigate Environmental Risks

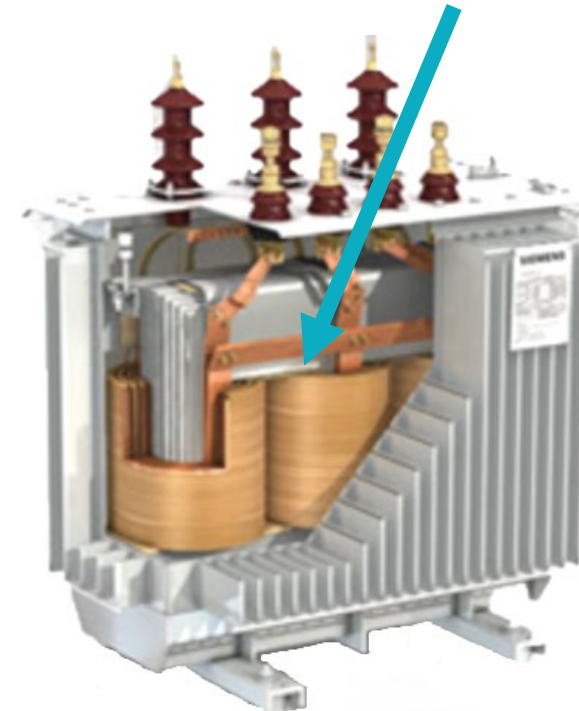
Speakers

- **Jinesh Malde** – Sr. Applications Engineer
MIDEL
- **Anthony Coker** – Executive VP Americas
MIDEL
- **Jon Tuck** – Business Development & Project Manager
Olsson Industrial Electric, Inc.

Transformers: The importance of liquid and the differences between MO and Synthetic Esters

- Liquid in transformer is an insulator and cooling medium.
- Historically mineral oil was used however synthetic ester has become an established dielectric liquid for transformers in the hydropower industry as it enables total cost of ownership (TCO) savings in substation designs.
- Mineral oil is highly flammable, toxic and not environmentally friendly

Internal Chamber filled with dielectric insulating liquid



What are Ester Liquids?

Synthetic Ester



Created through the reaction of an alcohol with short chain fatty acids

Natural Esters



Derived from the seed oil of soybean & canola plants

Synthetic vs Natural Esters

- **Oxygen Stability**
 - Synthetic ester suitable for sealed and breathing transformers
 - Natural esters suitable for sealed transformers
- **Cold Temperature Performance**
 - Synthetic ester suitable for cold climates
 - Natural ester has higher pour points, more suitable for temperate climates
- **Service History**
 - Synthetic ester introduced mid 1970s
 - Natural ester introduced late 1990s

Flammability Test: Synthetic Ester vs. Mineral Oil



Pool Fire Test: Synthetic Ester

Fluid type

- MIDEL 7131 Synthetic Ester

Test Performed on two transformers

- 250kVA
- 630kVA

Short circuit applied to ignition wire

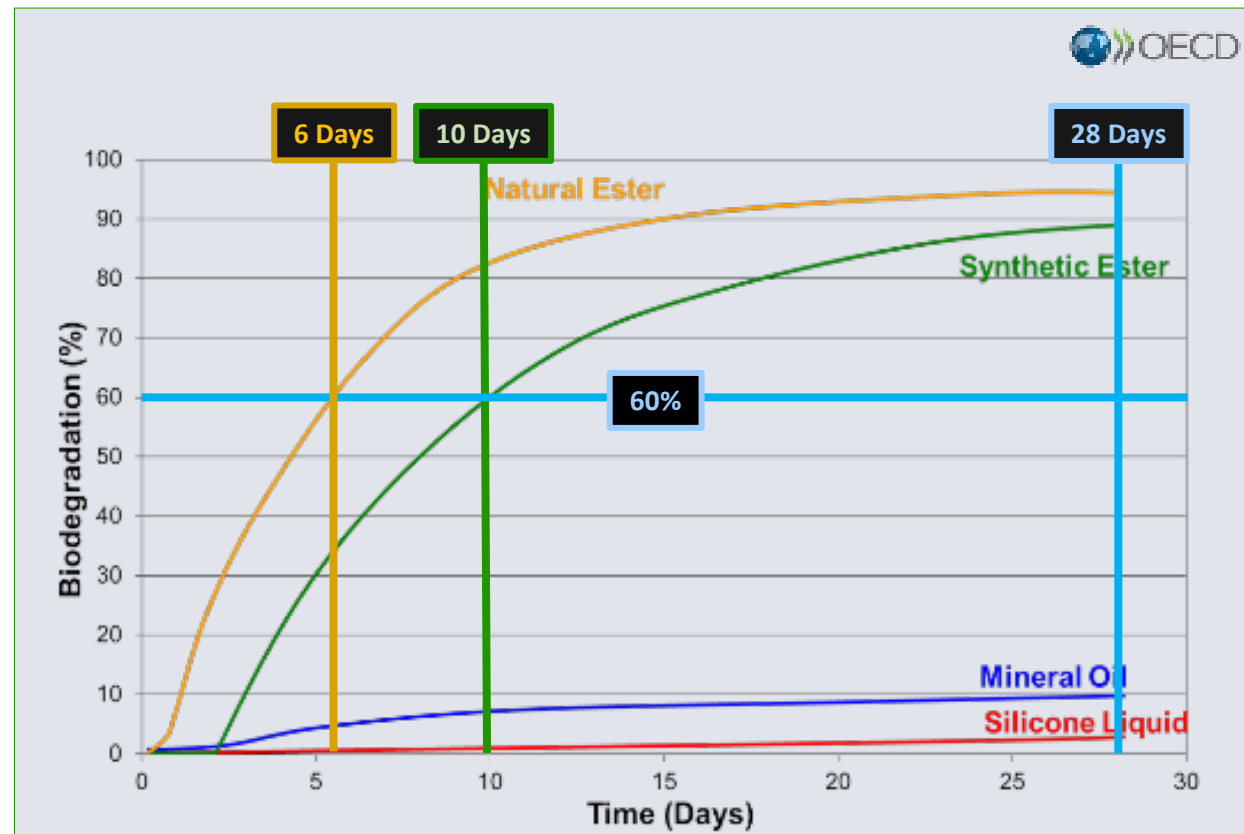
- 610ms 9.7kA 20.2kV



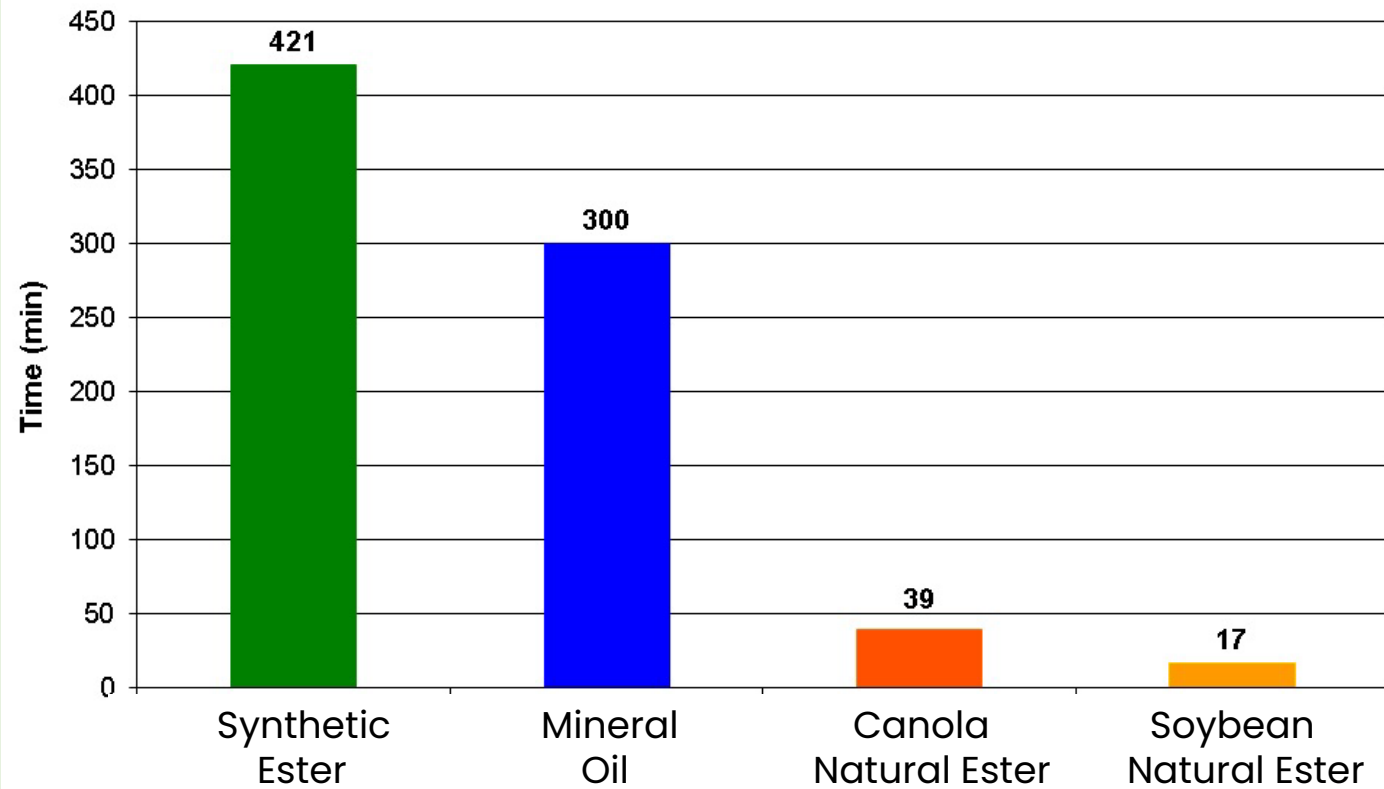
Biodegradability Test: Natural & Synthetic Ester vs. Mineral Oil & Silicone

Organization for Economic
Co-operation & Development
(OECD)

Biodegradability Test 301



Oxidation Stability Test: Results



- ASTM D2112
- Pressurised Vessel Test

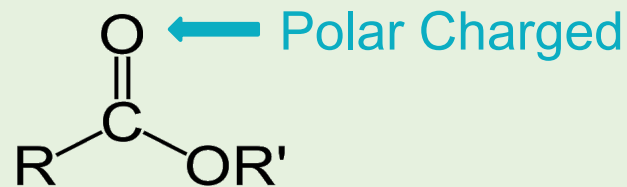


Ester Chemistry & Water

Water Structure

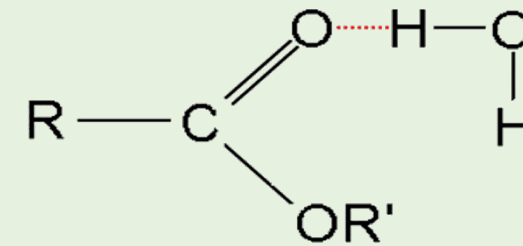


Binds Moisture



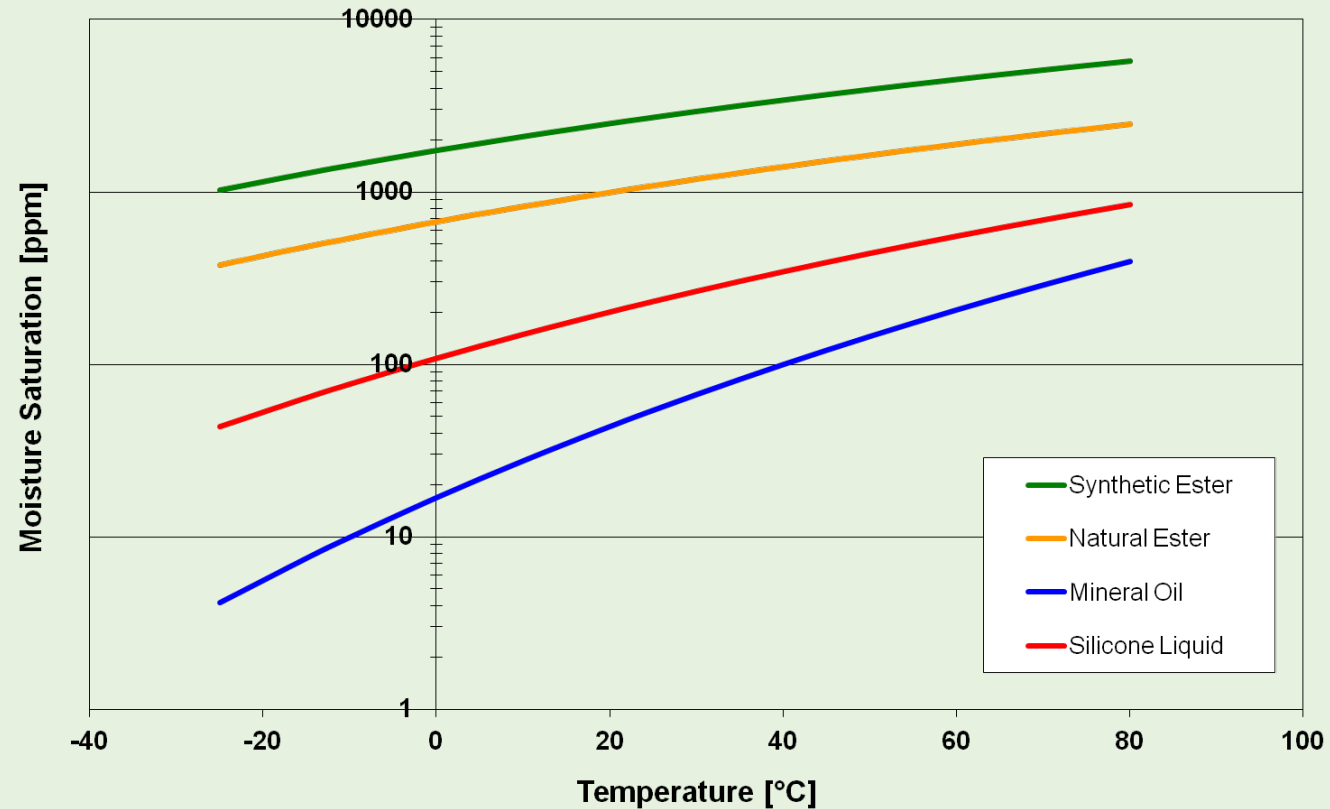
Basic Ester Structure

Hydrogen bond



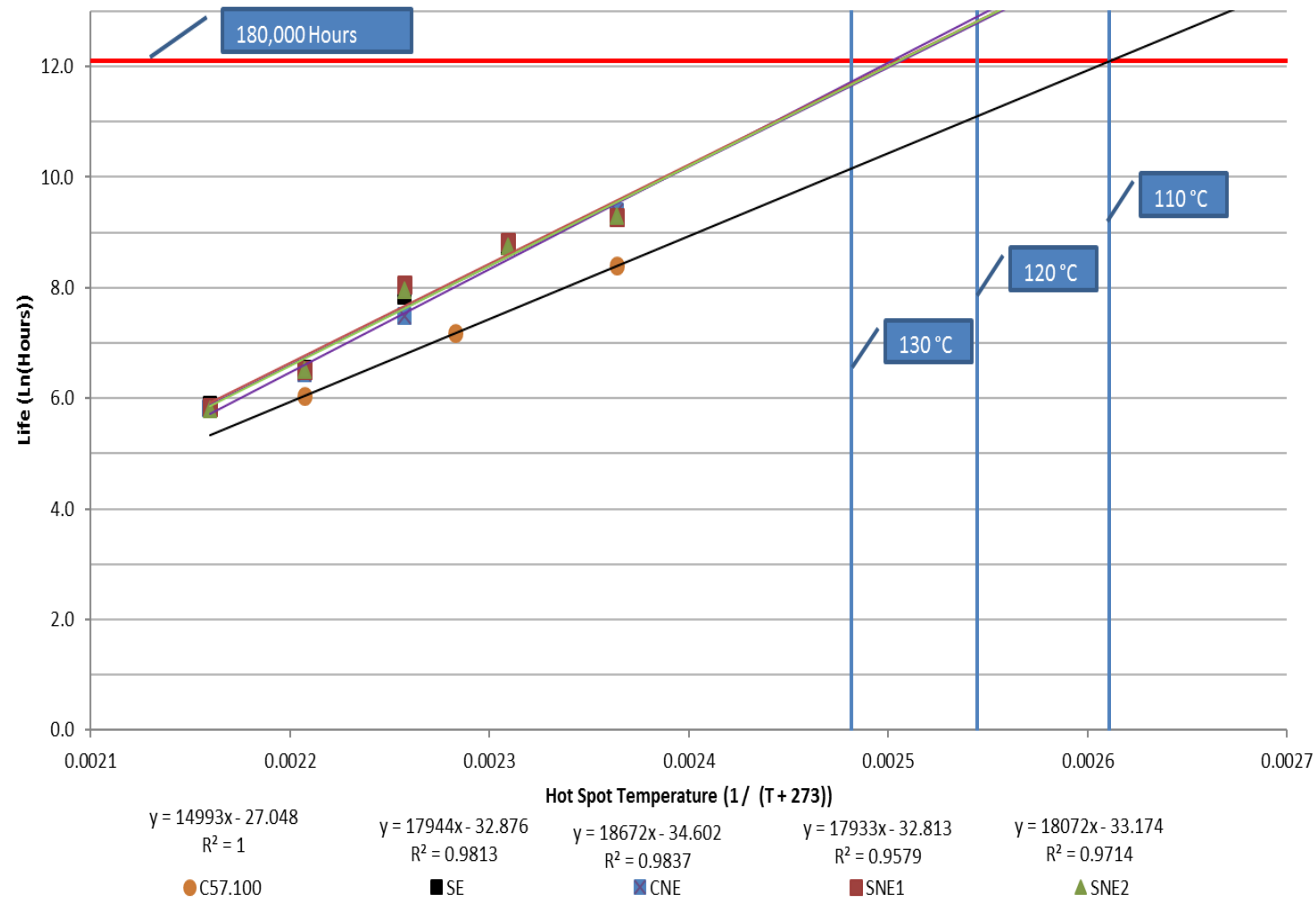
Hydrogen Bonding

Moisture Saturation Limit



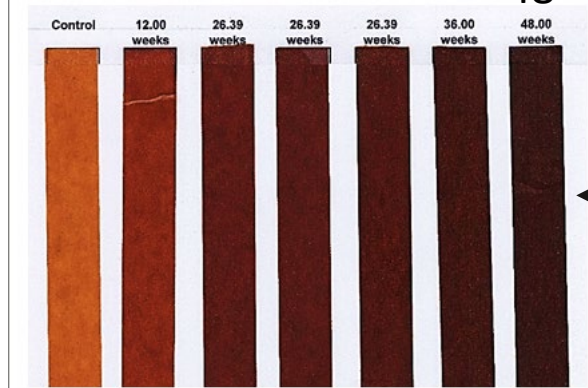
Paper Ageing & Esters

Thermal Index Estimation (Tensile Retention)



IEEE C57.100

a) MO Weeks @ 180C



Temperature 180°C

- Mineral Oil
- 48 Weeks

b) SE Weeks @ 180C



Temperature 180°C

- Synthetic Ester
- 100 Weeks

Benefit of Higher Thermal Class of Cellulose

- **Many laboratory studies have been carried out looking at paper ageing in esters**
- **IEEE and IEC have published guidance based on the results showing ester transformers in comparison to mineral oil can be:**
 - Smaller and lighter
 - Longer lifetime
 - Handle higher load



Making the Switch to Synthetic Ester

- References
- Transformer design differences
- Transformer maintenance requirements

Hydro References: Sweden

- Underground hydropower station Stalon
- World's first GSU transformer with synthetic ester – Built in 2004
- 135 MVA, 238kV
- Fire safety was crucial
- Space restriction
- Location in an environmentally sensitive location

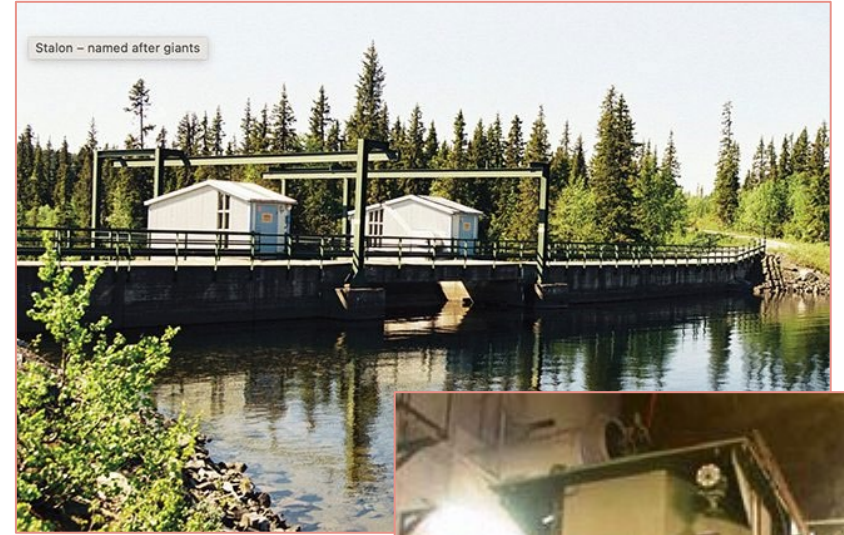


Photo Credit: Vattenfall



Hydro References: Sweden

- Letzi Power Plant has four single phase Generator Step Up units for hydro plant
- Transformers rated at 122MVA, 433kV
- Highest voltage class transformers filled with ester liquids.
- Transformers in service 2016
- Synthetic ester chosen for fire safety, space restriction and environmental reasons



Photo Credit: [https://vekuvaku.eu/river/lule-river/power-plant/letsi/](https://vekuvaku.eu/river/lule-river/power-plant/letzi/)

Synthetic Ester: Rated Highest by US Bureau of Reclamation

2019 R&D Study – “Alternate Insulating Fluids for Power Transformers”

1. Mineral Oil
2. SF6 Gas
3. Synthetic Ester
4. Soy Natural Ester
5. Canola Natural Ester

Five Topics of Concern Rated as:

- Advantage
- Disadvantage
- Neutral

“In summary, it was found that **natural and synthetic ester fluids**, even at high concentrations, **do not kill fish.**” (Page 21)

Table 1 - Summary of Insulating Fluids

Topic	Mineral Oil	Natural Ester Fluid	Synthetic Ester Fluid	SF ₆ Gas
Fire Safety	Disadvantage	Advantage	Advantage	Advantage
Environmental Impact to Waterways	Disadvantage	Advantage	Advantage	Advantage
Life Expectancy	Disadvantage	Advantage	Advantage	Neutral
Oxidation Stability	Advantage	Disadvantage	Advantage	Advantage
High Temperature Operation	Disadvantage	Advantage	Advantage	Neutral

RECLAMATION *Managing Water in the West*

Alternate Insulating Fluids for Power Transformers

Research and Development Office
Science and Technology Program
(Final Report) ST-2019-100-01

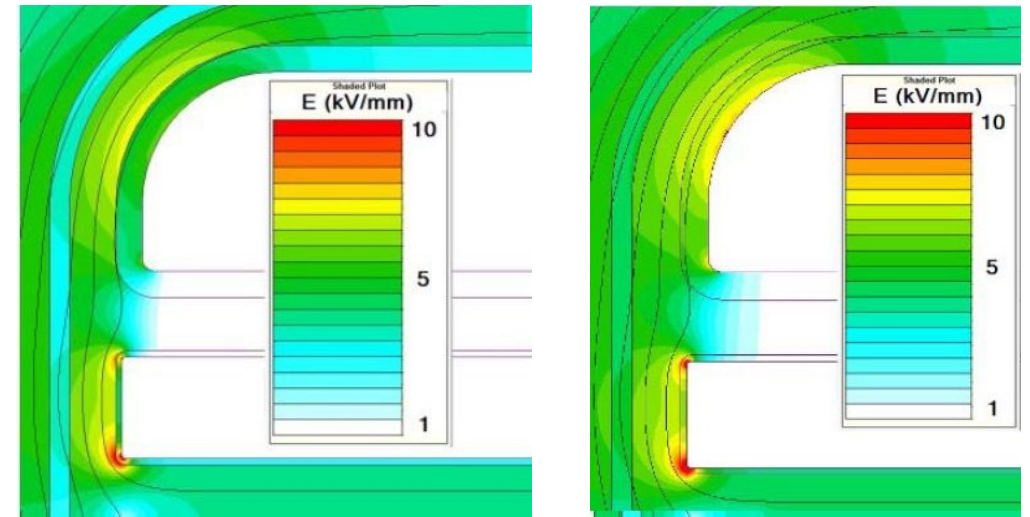


U.S. Department of the Interior
Bureau of Reclamation
Research and Development Office

October 1, 2019

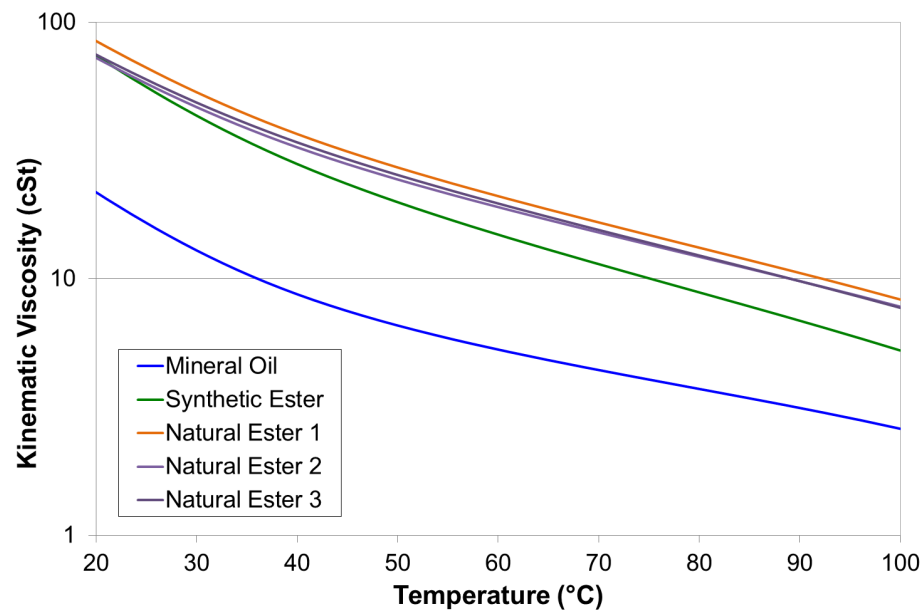
Synthetic Ester Vs Mineral Oil: Transformer Design, Dielectric Design

- **Impulse strength of esters is lower than mineral oil**
 - Especially true at large gap distance / inhomogeneous arrangements
 - Avoid highly stressed long oil gaps
 - Introduce more barriers to break up
- **Permittivity of esters is different**
 - Needs to be considered during design
 - Should reduce stress in fluid
 - May increase localised stress in paper structures
- **Combination of these effects means design changes**
 - Increase of insulation in highly stressed regions
 - Smoothing of curve radii of structures to reduce stress



Ref: Transformer Insulation Structure for Dielectric Liquids with Higher Permittivity, ICDL 2017

Synthetic Ester Vs Mineral Oil: Transformer Design, Thermal Design



	Mineral Oil	Synthetic Ester	
Hot Spot	69.8K	77.4K	80.0
Winding Rise	8.4K	8.0K	78.5
Winding Temp	47.6K	49.8K	77.0
			75.5
			74.0
			72.5
			71.0
			69.5
			68.0
			66.5
			65.0
			63.5
			62.0
			60.5
			59.0
			57.5
			56.0
			54.5
			53.0
			51.5
			50.0

Synthetic Ester Liquid Transformer Design Options

	Mineral Oil with Kraft or Thermally Upgraded Kraft	Synthetic Ester Liquid with Kraft or Thermally Upgraded Kraft	Synthetic Ester Liquid with Thermally Upgraded Kraft	Synthetic Ester Liquid with Enhanced Cellulose Insulation	Synthetic Ester Liquid with High Temperature Solid Insulation
Fire Safety	X	✓	✓	✓	✓
Environmental protection	X	✓	✓	✓	✓
Longer Lifetime	X	✓	✓	✓	✓
Overload	X	X/✓	✓	✓✓	✓✓✓
Smaller footprint	X	X	✓	✓✓	✓✓✓

Power Transformer Design with Synthetic Esters

- **Thermal aspects**
 - Higher/wider key-spacers and/or more radiators, fans
 - Due to the viscosity
 - Lower load loss to get the same temperature rising (as mineral oil)
- **Electric**
 - Larger clearances inside the transformer
- **Special tap changer, bushings, pumps**
- **Basically, the gaskets, sealing are usable**
- **Care with cold starting of the transformer**
- **With agreement: higher load loss, higher temperature rising with higher temperature class insulation, smaller dimensions**

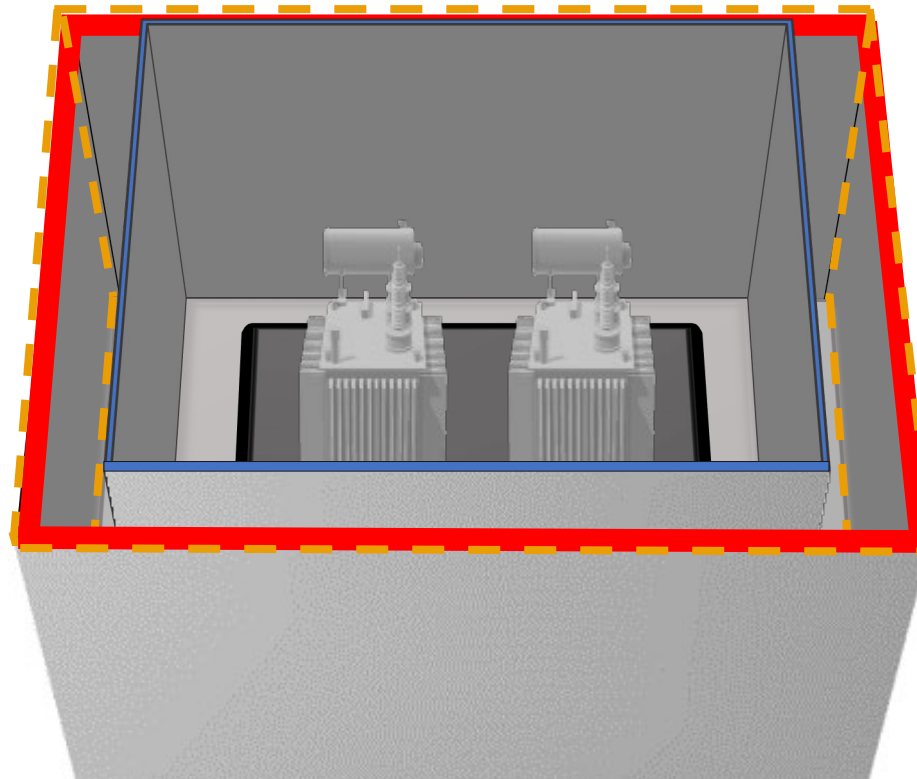
FM Global Guidance: Indoor Transformers

Mineral Oil-Filled Transformers

- Room with 3-Hour Firewalls
- Separated by 3-Hour Fire Barriers
- Individual Containment
- Fire Suppression System
 - Drainage System

- ✓ Up to 80% Footprint Reduction
- ✓ Quicker Build Time
- ✓ Fewer Materials

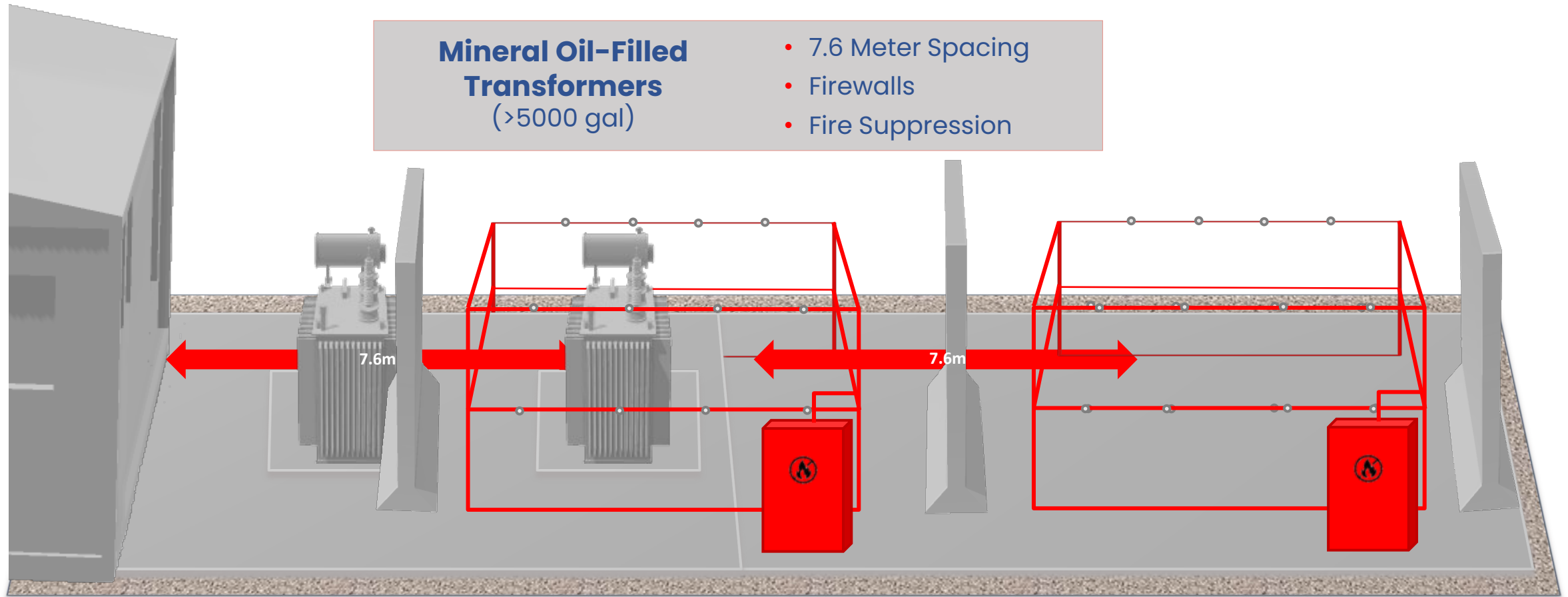
Lower TCO



Ester-Filled FM Approved Transformers

- No Fire Suppression
 - ✓ No Drainage System
- No Fire Barriers
- Shared Containment
- Less Space Required Between Transformers
- Room with Unrated Walls

FM Global Guidance: Outdoor Transformers Adjacent to Buildings



Conceptual Illustration – Not to Scale

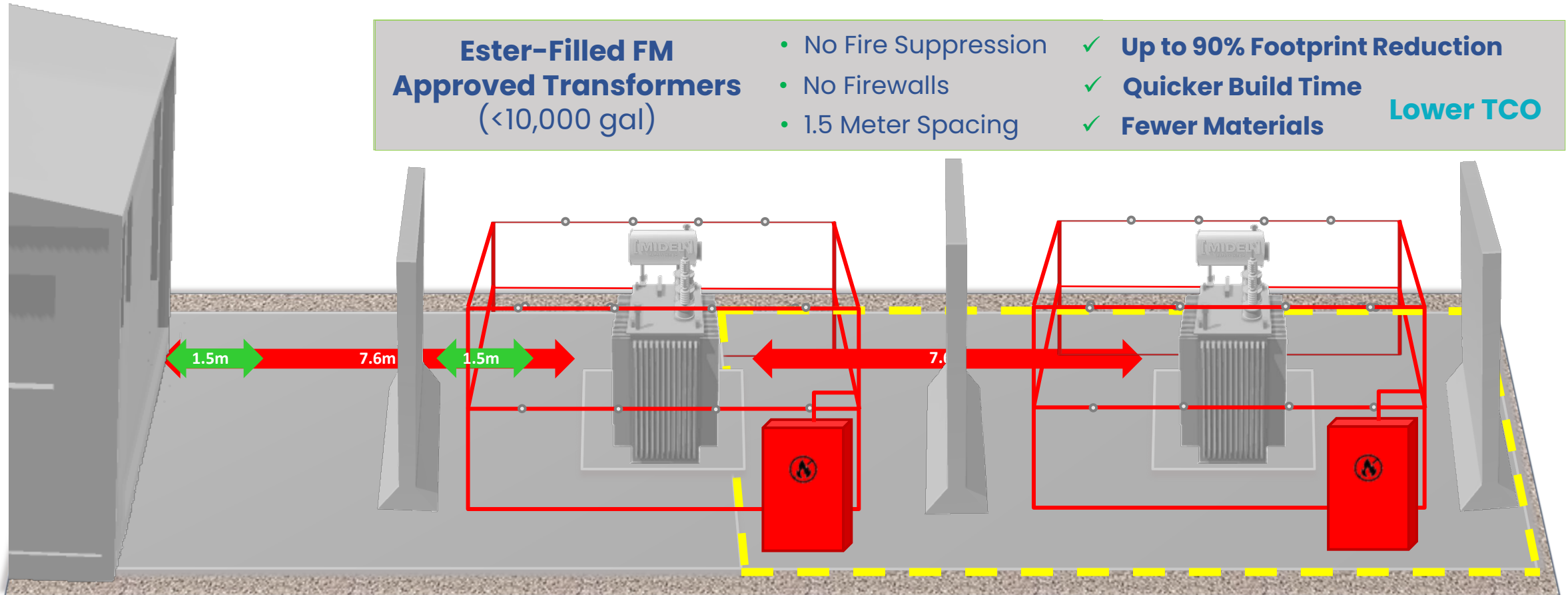
FM Global Guidance: Outdoor Transformers Adjacent to Buildings

Ester-Filled FM Approved Transformers (<10,000 gal)

- No Fire Suppression
- No Firewalls
- 1.5 Meter Spacing

- ✓ Up to 90% Footprint Reduction
- ✓ Quicker Build Time
- ✓ Fewer Materials

Lower TCO



Conceptual Illustration – Not to Scale

Wells Hydro Project: Douglas County PUD

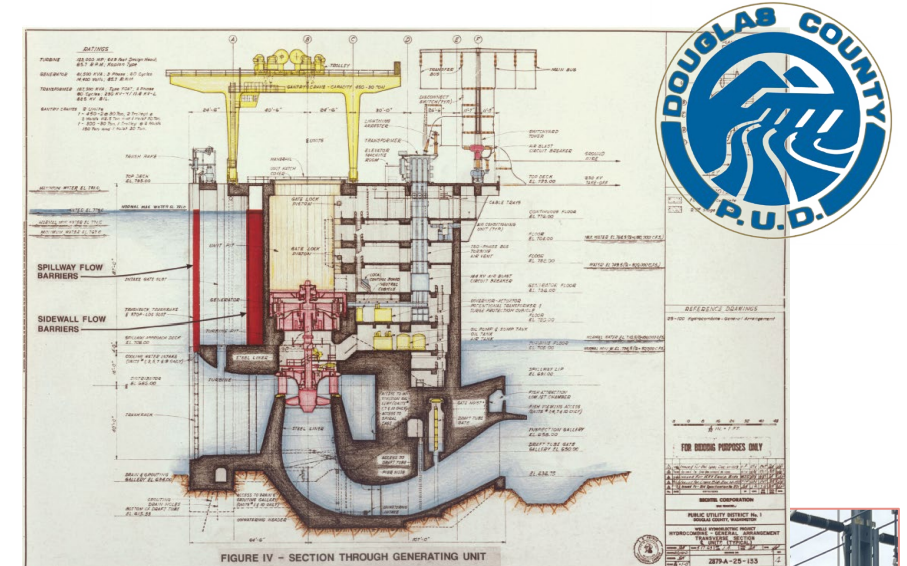
- Douglas County is developing a renewable hydrogen fuel production facility
- The facility will be powered by electricity from Douglas County PUD's Wells Hydro Project power plant
- Wells Hydro plant requires 5 new GSU units (existing GSU's are 1960's era)
- A thorough evaluation determined **MIDEL 7131 synthetic ester** as the best fluid for the PUD's sizable investment, and was specified by name
- Total project cost estimate: >\$30M
- **Olsson Industrial Electric** selected by Douglas County PUD, and work has begun, with completion expected in 2026



Photo Credit: Wells Project

Wells Hydro Project: Existing Equipment & Conditions vs. Future Needs

- Douglas County Public Utility District (PUD) located in Washington state recognized a need to replace the aging generator step-up (GSU) transformers located at the Wells Dam and saw it as an opportunity to consider innovative solutions.
- Existing GSU is a GE Pittsfield 188MVA 13.8–230kV Mineral Oil Insulated COPS Tank design
- Installation on the Hydrocombine structure on the deck above the Columbia River
- Containment design drains to common oil water separator on the West end of dam
- 230kV Switchyard Structural Steel and Bus directly over the GSU's



Wells Hydro Project: Evaluation & Selection of Synthetic Ester

- PUD engineers evaluated different technologies for transformers to improve plant reliability, reduce the risk of outages, and mitigate the risks of fire, water contamination and environmental harm. Based on their evaluation, they selected synthetic ester over mineral oil transformer dielectric liquid.



Wells Hydro Project: Reasons for Choosing Synthetic Ester



- Higher biodegradability being better for the environment than mineral oil, should there be a leak/spill.
- The higher flash & fire point to provide additional safety should anything catastrophic happen.
- Wells Hydro is a unique setup with the 230kV switchyard on the dam, directly above the transformers.
- In theory, during a catastrophic event the higher flash & fire point would mitigate damage to the switchyard and surrounding equipment.
- Douglas County PUD chose synthetic ester rather than natural ester for the following reasons:
 - Concerns with storing the oil and the potential for crystallization of ester oil when exposed to oxygen.
 - On the crystallization point, we have drains in our transformer containment that connect to our oil-water separator on the west end of the dam.
 - If there was a leak & the ester happened to crystallize in the drainpipe it would create an even larger issue.

Wells Hydro Project: Next Steps



- First unit is en route, shipped on Sep 25, ETA 15 Nov
- Arrival to Port of Tacoma and then road haul to Wells Dam
- Inspections on Arrival at Port and after road haul include
 - Physical checks for damage
 - SFRA, Dew Point, Impact Recorder, Lat -Lon Device, Core Ground Insulation Resistance
- Delivery to storage yard, install window for 1st unit is Feb/Mar 2025
- Ester Oil arrives in 20,000 Liter bulk tank from Midel, Ester to arrive Feb

Wells Hydro Project: Next Steps



- Old units jack and slide to crane for transit to truck, reverse for new units into the vault
- Old T5 becomes the 'new' spare, existing spare is a McGraw Edison which will be scrapped – contact me if you are interested in acquiring for details
- With GSU's, also replacing Isolated Phase Bus (IPB) from LV Bushing Housing to the deck. IPB 8600A at 15kV rated
- GSU and IPB Seismic Zone qualified by Manufacturer, Olsson provides Seismic Anchorage Design
- Remaining 4 units all ship in 2025, installation during scheduled Generating Unit outages in Spring/Fall 2025 and 2026
- Completion scheduled October 2026

Making the Switch to Synthetic Ester: Summary



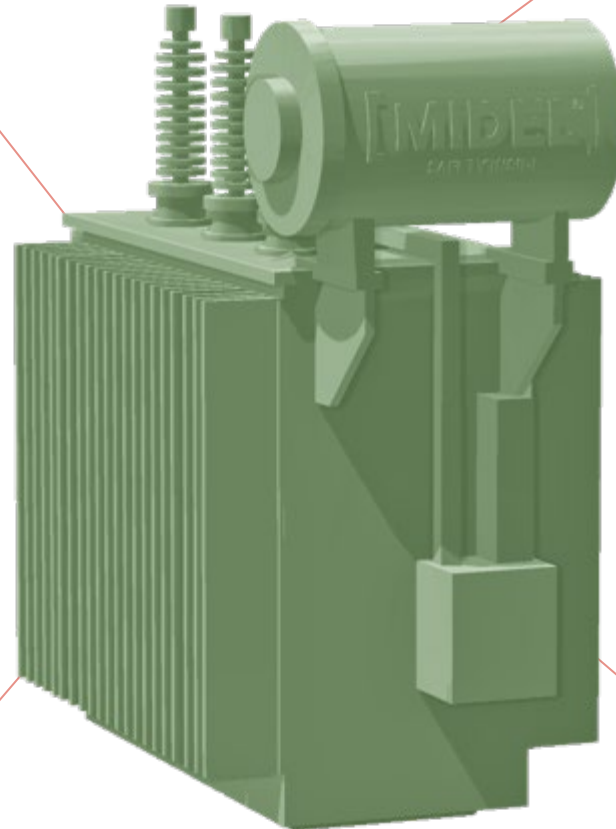
Reduces Owner Risk & Insurance Costs

Fire Resilience, Personnel Safety



Lowers Environmental Harm

Biodegradable fluid, Non-toxic



Increases Performance

Hot Running, Sustainable Overloading



Delivers Higher ROI

Improved Reliability, Longer Life



Thank You! Q&A

Jinesh Malde

Sr. Applications Engineer – MIDEL

jineshmalde@midel.com | 404-900-9229

Anthony Coker

Executive VP Americas – MIDEL

anthonymcoker@midel.com | 404-808-0025

Jon Tuck

Business Development & Project Manager – Olsson Industrial Electric, Inc.

jon.tuck@olssonelec.com | 541-510-8908