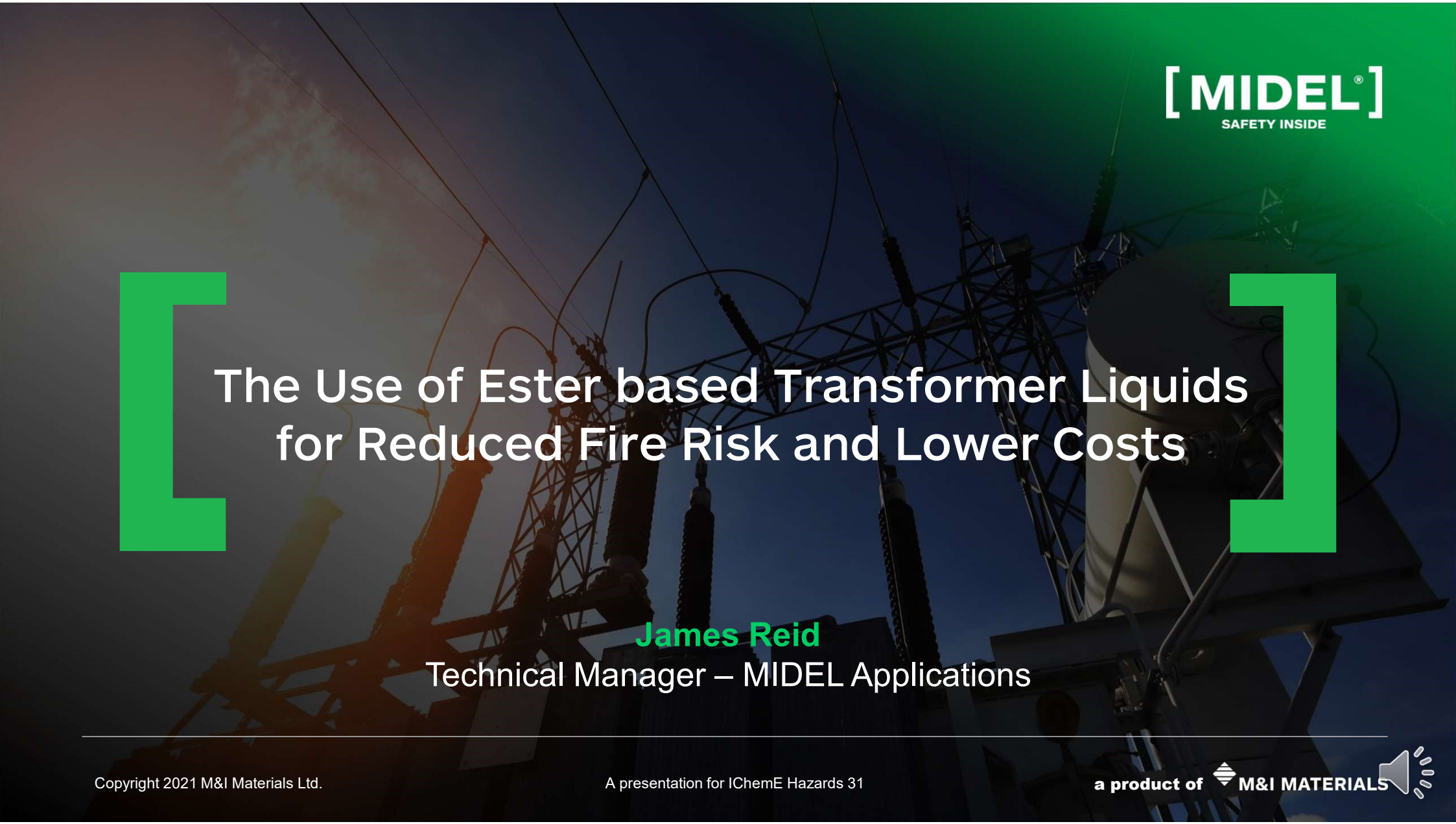


The Use of Ester based Transformer Liquids for Reduced Fire Risk and Lower Costs

James Reid
Technical Manager – MIDEL Applications

A presentation for IChemE Hazards 31

a product of M&I MATERIALS

Introduction

Risk of Transformer Failure

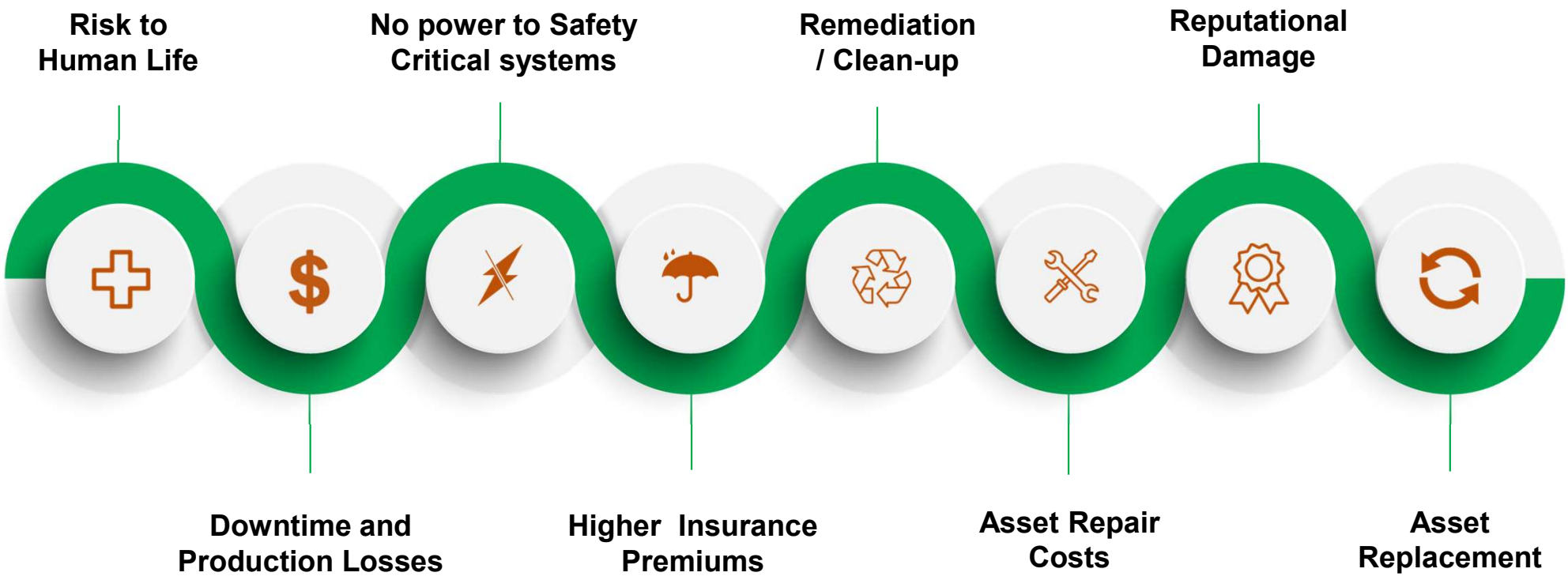
- CIGRÉ, 2013
  - Probability of fire ~0.1% per year
  - Over typical 40 year lifetime → **average probability 4%**
- Berg, 2015
  - 37 of 438 fire events (8%) in nuclear power plants in oil filled transformers
  - **"Transformers are the most frequent fire source"**
- Bartley, 2003
  - 3 of 94 failures (3.2%) due to transformer as victim of external fire/explosion
  - US$8m paid by insurance

Germany: Nuclear Power Station, Krümmel 2007

Mount Isa Mines, Queensland, 2017

Source: https://www.northweststar.com.au/story/4936376/exploding-transformer-caused-fire-on-mine-site/

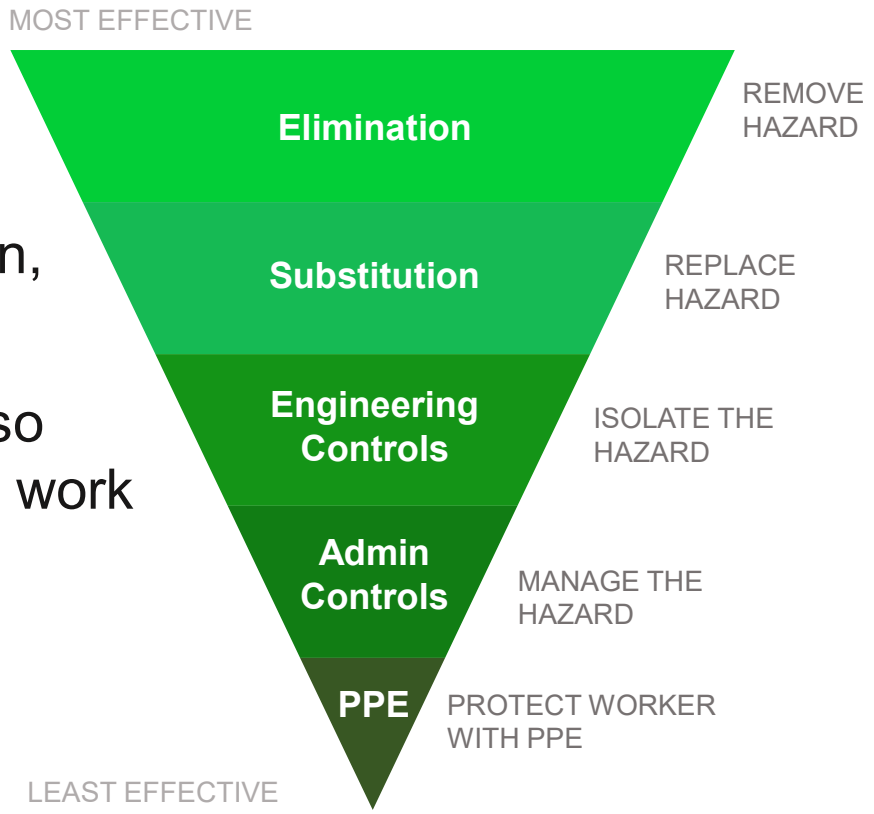
Why address Inherent Risk with Mineral Oil Transformers?

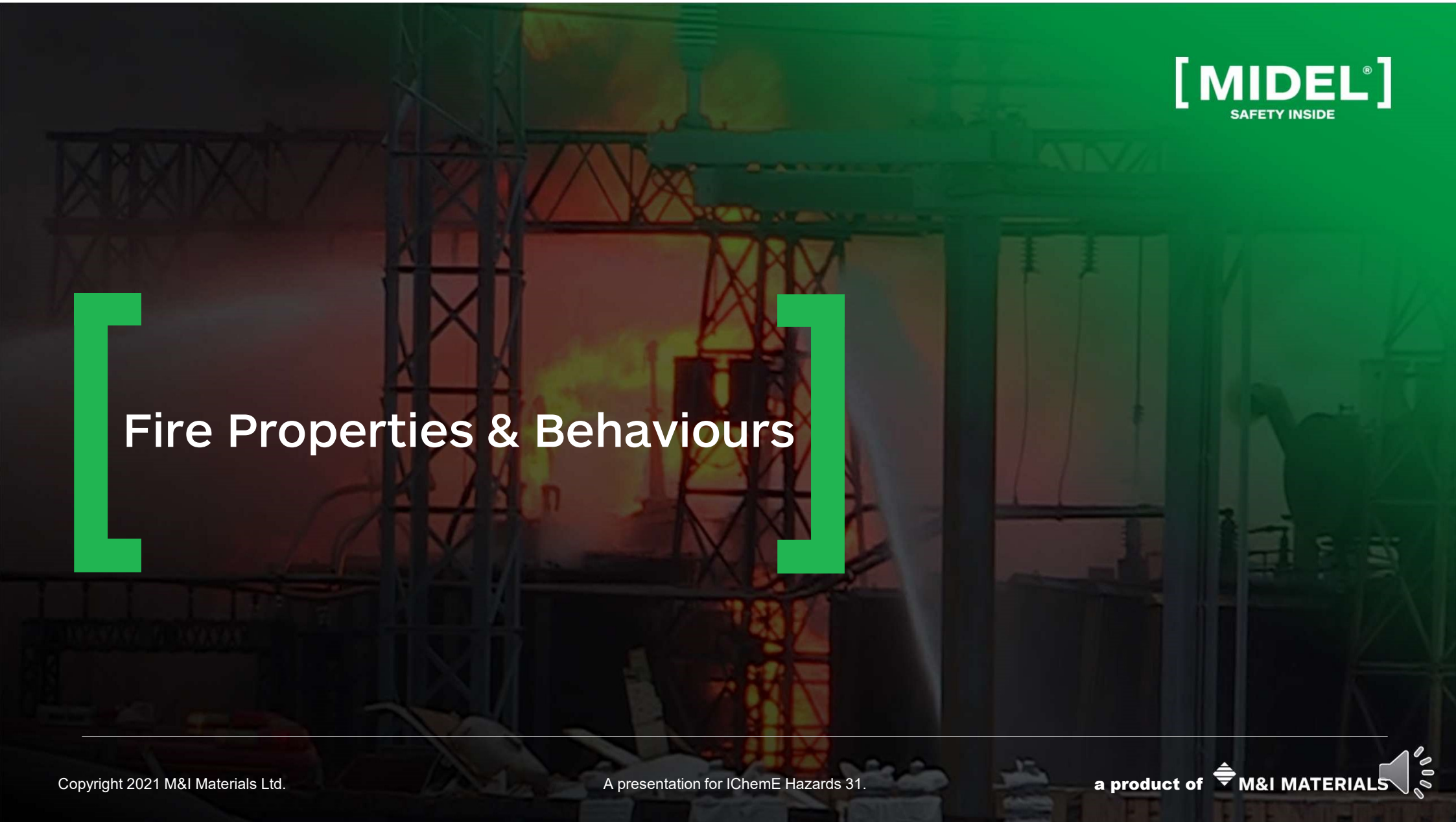


Hierarchy of Safety Controls

A widely accepted methodology for minimising or eliminating workplace hazards

- Mineral Oil “Best practice” relies on Engineering Controls (e.g. fire suppression, containment)
- These secondary engineering systems also require Admin Controls to make sure they work on demand





Fire Properties & Behaviours

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Hazard Classification of Insulating Liquids

[MIDEL®] SAFETY INSIDE

- Classification of insulating liquids according to IEC 61039

Fire Point		Low Heat Value	
O	≤300°C	1	≥42MJ/kg
K	>300°C	2	<42MJ/kg
L	No measurable fire point	3	<32MJ/kg

- Typical fire properties & hazard classification of dielectric liquids

Dielectric Liquid	Flash Point ISO 2719	Fire Point ISO 2592	Low Heat Value	Classification to IEC 61039
Mineral Oil	150°C	170°C	46.0MJ/kg	O1
Natural Ester	316°C	360°C	37.5MJ/kg	K2
Synthetic Ester	260°C	316°C	31.6MJ/kg	K3

Energy Required To Reach Fire Point

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- A typical transformer operates at ~80°C
- Assuming no heat loss from the transformer, **~3 times more energy** is required to reach fire point

Dielectric Liquid	Mass of 1000l	Specific heat capacity	Temperature change	Energy to raise liquid temperature to fire point
Mineral Oil	**880kg**	**1860J/kg °C**	**90°C**	**147MJ**
Natural Ester	**920kg**	**1848J/kg °C**	**280°C**	**476MJ**
Synthetic Ester	**970kg**	**1880J/kg °C**	**236°C**	**430MJ**

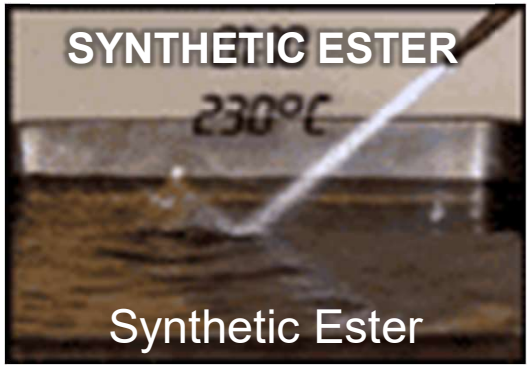
Transformer Fluids Comparison

Flammability Under Controlled Tests

3 mins

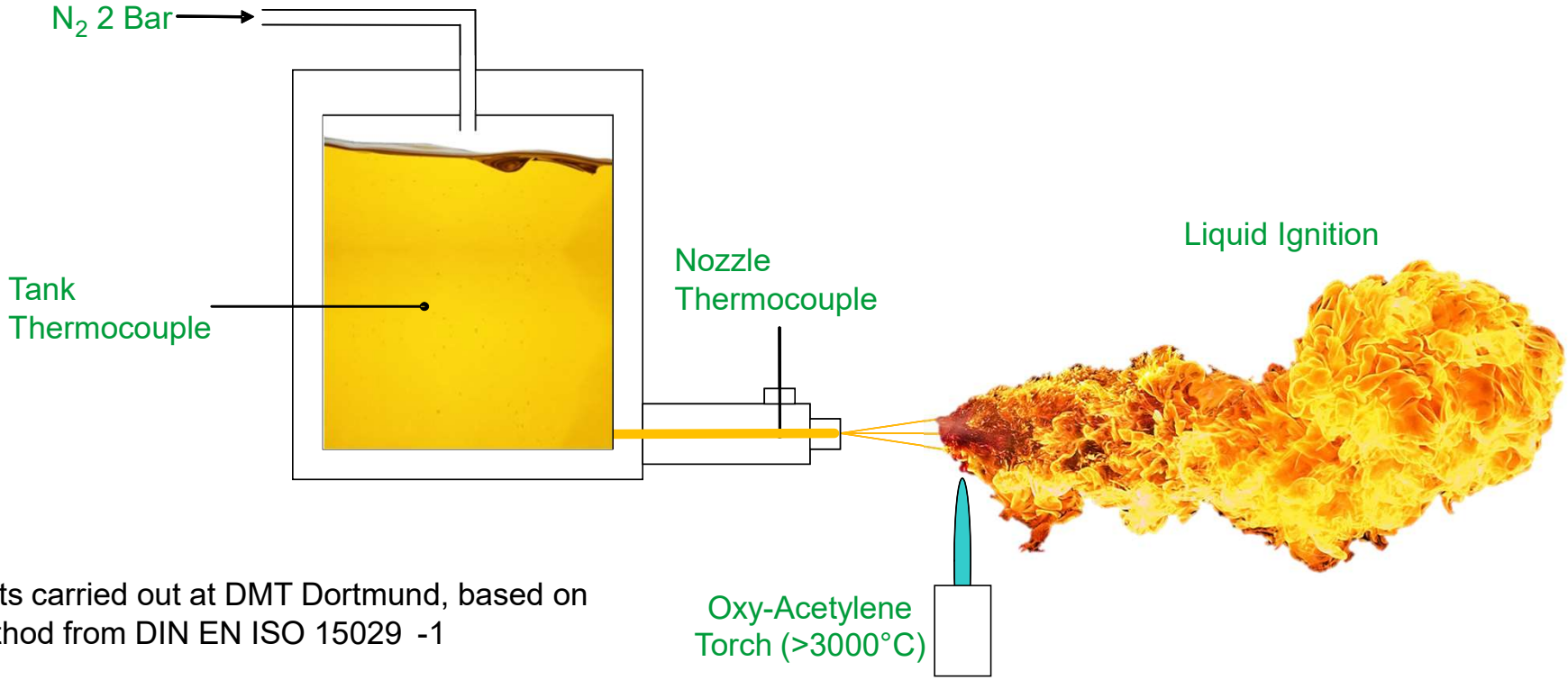
4 mins

3 mins



70 mins

Spray Ignition Test Set Up



Tests carried out at DMT Dortmund, based on method from DIN EN ISO 15029 -1

Mineral Oil vs Synthetic Ester in Spray Ignition Test

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Mineral Oil. Nozzle temp **112 ºC**

Synthetic Ester. Nozzle temp **120 ºC**

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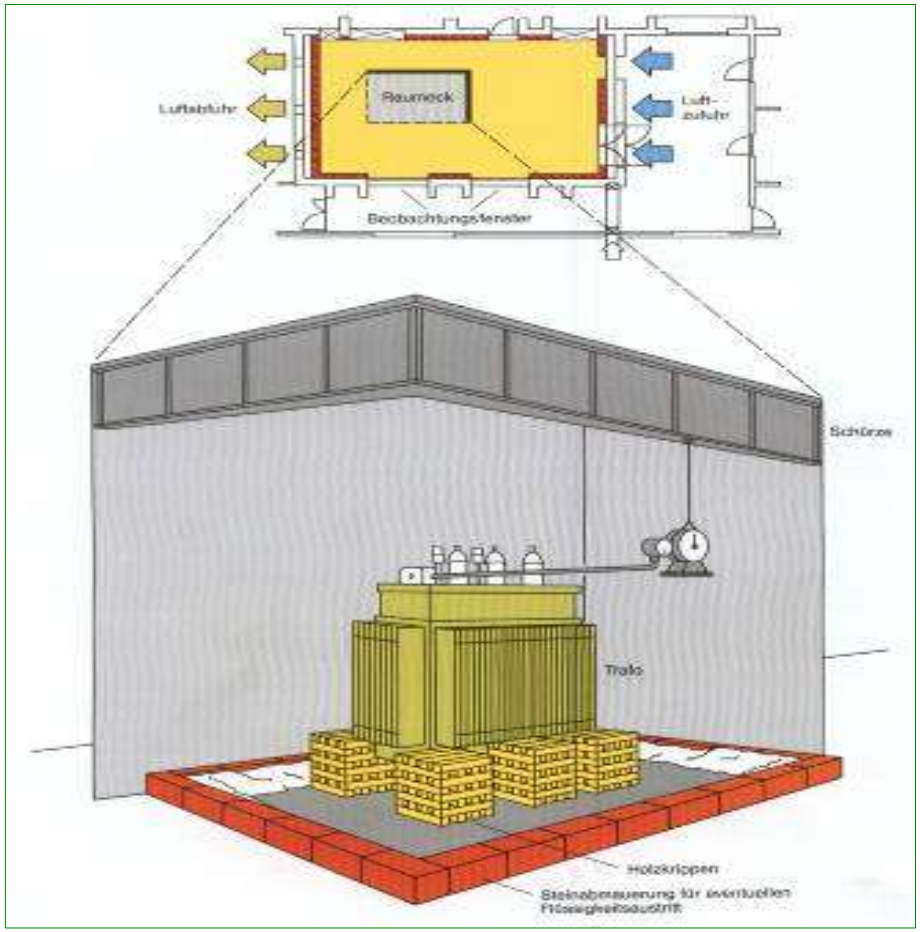
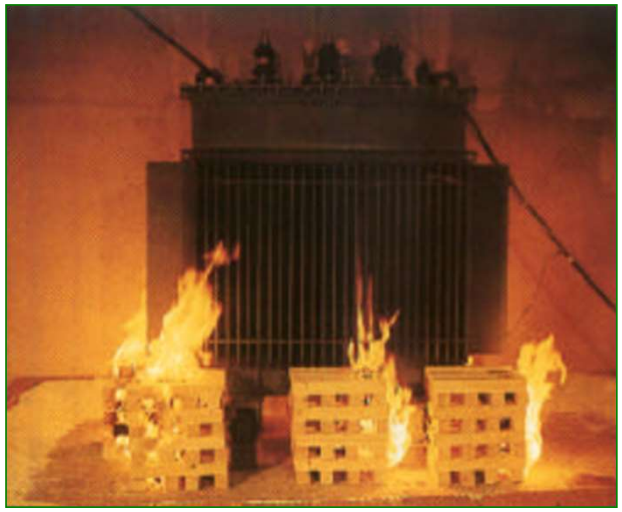
Full Scale Fire Test – Allianz, Germany



- 630kV transformer (365kg ester)
- Floor area 10m X 6m
- Fire load 180kg pre-dried cribs

Fire Test Summary



- Transformer subjected to external fire for >70mins
- Internal temperatures
  - peaked at 180°C (bottom) & 204°C (top)
  - always well below flashpoint (260°C)
- No dangerous operating state arose
- No cracks or leaks
- Transformer did not contribute to the fire
- Transformer was still in electrical working order

Insurance approvals

KEY

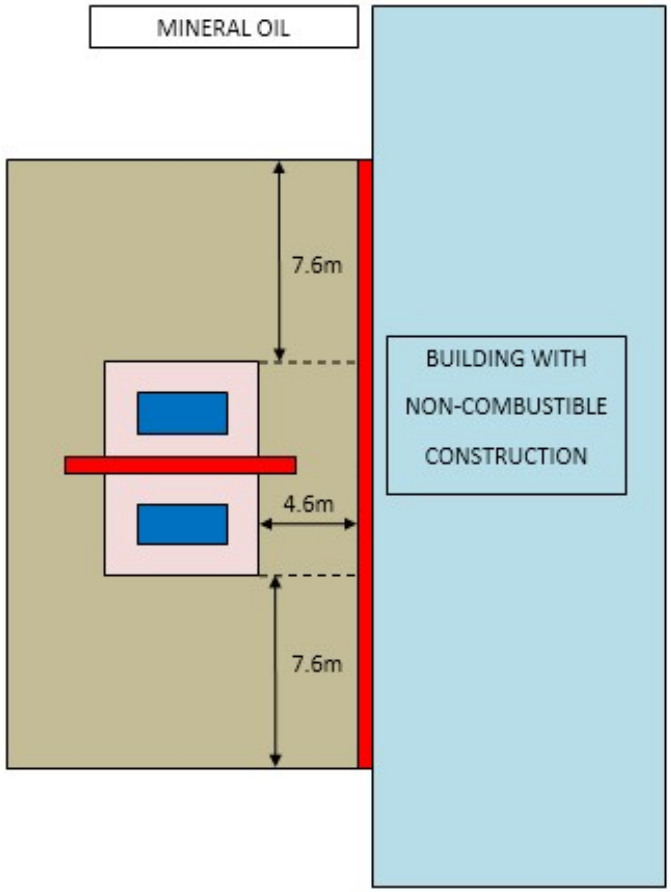
- MINERAL OIL TRANSFORMER
- ESTER TRANSFORMER
- CONTAINMENT
- 2-HOUR FIRE RESISTANT BARRIER
- AREA OF SUBSTATION

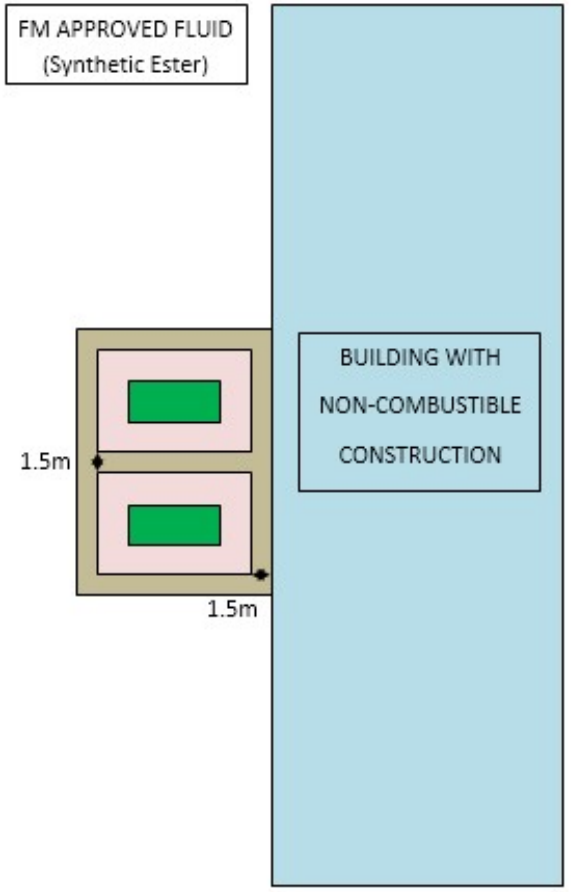
NOTES

TRANSFORMERS CONTAIN BETWEEN 1,900 AND 19,000l OF FLUID

SPACING BASED ON FM GLOBAL DATASHEET 5-4, APRIL 2021

SPACING BASED ON FIRE CLEARANCES ONLY





International Standards

- IEC 61936-1, AS2067 and NFPA 70 also allow reduced clearances or protection for K Class liquids
- Table gives example of clearance reduction for transformer containing 3,000 litres as per IEC 61936
- Enhanced protection includes high & low current fault protection, tank strength and PRV common on transformers from reputable OEM

Transformer Type	Location	Clearance to other transformer	Clearance to combustible surface
Oil Insulated (O Class)	Outdoors	5m	10m
Less flammable liquid (K class) with enhanced protection	Outdoors	0.9m	1.5m

Swiss Institute for Promotion of Safety & Security (SWISSI)

[MIDEL® SAFETY INSIDE]

- Independent study into fire safety comparison of synthetic ester with mineral oil
- Three safety targets
  - If transformer totally destroyed by fire, neighbouring plant or transformers should remain thermally intact
  - Fire damage due to electrical fault avoided or highly unlikely
  - A 10MW fire in the immediate area should not impair transformer function

	Scenario	Fire Safety System
1	Transformer outdoors with protective screen	Dielectric liquid with Nitrogen extinguishing system
2	Transformer outdoors without protective screen with little safety clearance	Dielectric liquid with water deluge system
3	One transformer in a room (fire sector)	Dielectric liquid with spray extinguishing system
4	Several transformers in a same room (fire sector)	Dielectric liquid without extinguishing system

SWISSI Study Findings

[MIDEL®] SAFETY INSIDE

	No extinguishing system				"Conventional" gas extinguishing systems (N_2/CO_2)				"Conventional" water deluge systems				Spray – High-pressure extinguishing system (>75bar)			
Scenarios	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
a – Oil	+	-	+	-	+	-	+	-	+	+	+	+	+	+	+	+
a – Ester	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
b – Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
b – Ester	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
c – Oil	+	-	+	-	+	-	+	+	+	+	+	+	+	+	+	+
c – Ester	+	-	+	+	+	-	+	+	+	+	+	+	+	+	+	+

- Only two cases where ester probably would not meet criteria are as a victim of 10MW fire where transformer located outdoors with little safety clearance
- These can be addressed through appropriate inherent safety design considerations

Ester History and Case Studies

Improving fire safety and sustainability in transformers since 1978

1978 - British Steel Furnace Transformers

1989 - Rail Tunnel Hong Kong

2001 - First Wind Turbine applications

2014 - ITER Fusion reactor

2020 - Transnet BW 420kV (Rapeseed)

1982 - First Offshore Oil & Gas applications

1996 - DB B2185 Locomotives

2007 - CRRC High Speed Rail, China

2016 - Letsi Hydropower Station

1970's - 1980's; Retrofilling and DT

1999 – 110kV

2016 – 400kV+

1975 TODAY

1990 – Small power transformers

2004 – 238kV

2020 – Evaluation of HVDC and 500kV+

1981 – AMTRAK Retrofills

1992 - Vattenfall, Berlin Retrofills

2004 - 238kV Vattenfall

2016 - Highbury 400kV

2021 - India's first synthetic transformer, 220kV

1987 - Marine QEII Cruise Ship

1999 - 110kV Poland

2012 - KWO Oberhasli

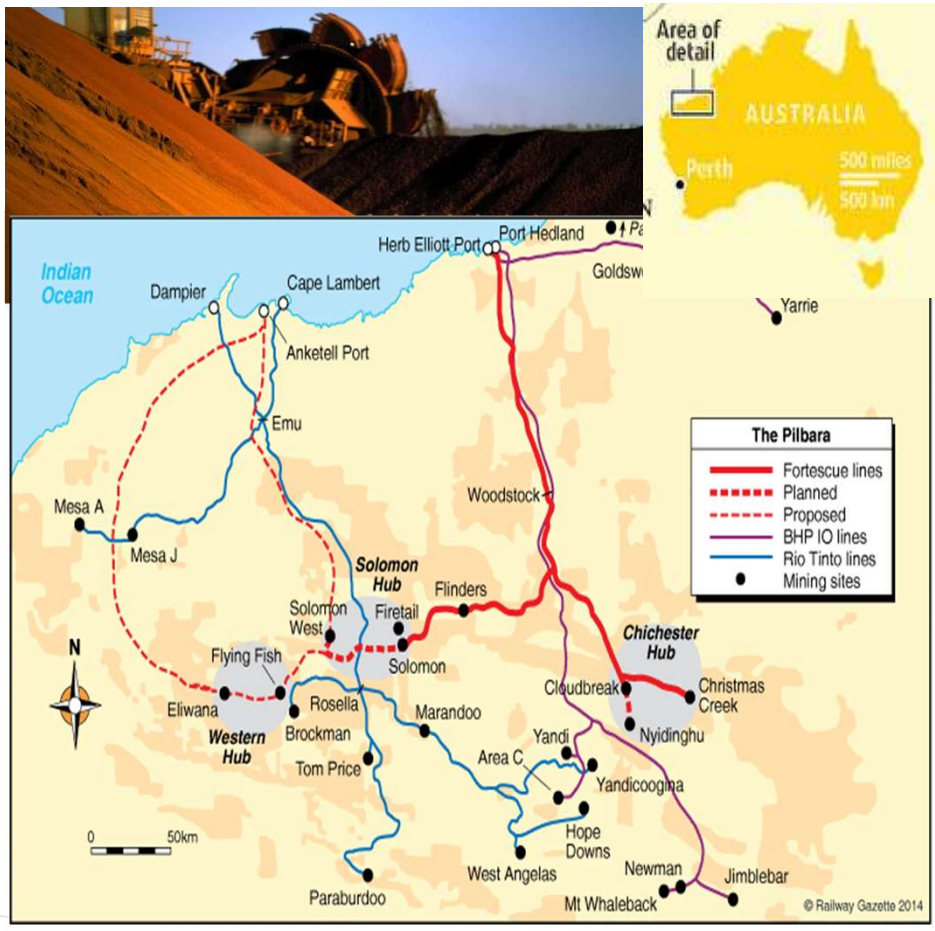
2017 - ConEd Mobile Power, New York

LNG Site, Yamal, Russia

- Challenging location inside arctic circle
  - Low temperatures (below -50°C)
- Generation plant located centrally & power distributed across site
  - 20 transformers up to 115kV & 125MVA
- Synthetic esters chosen with fire safety as an important consideration

Rio Tinto Koodaideri, Australia

- The development of a new iron ore mine and associated rail infrastructure extending from the Koodaideri mine to Rio Tinto's existing rail network. AUD $2.6 Billion investment.
- Project included 34 distribution transformers (33kV), and one 220kV power transformer.
- Worley Parsons (project EPC) specified MIDEL 7131 for all transformers.
  - "Why wouldn't you specify MIDEL. It completely de-risked the project and **saved over AUD3 million** in concrete."
- Rio now specifying esters (MIDEL 7131 preference) for all brownfield distribution transformers.



OQ Chemicals, Germany

- Site producing volatile chemicals
  - Fire in this plant could be “catastrophic for people, facility and assets”
- Two on site distribution transformers
  - Mineral oil filled
  - Delivering power to part of manufacturing plant
- Retrofilling with synthetic ester delivered benefits consistent with company’s approach to safety and business continuity

Mangalore Chemicals & Fertilizer Ltd, India

- 3.3kV, 1.6MVA transformer
  - 38 years old
  - Weakened solid insulation due to humid climate
  - Limited window for work to minimise disruption
- Options considered:
  - Capital replacement
  - Retrofill with synthetic ester
- Chose retrofill option
  - Completed work in less than 24hrs
  - Independently confirmed K class fire point result

Ethylene Treatment Plant, USA

- 1500kVA transformer
  - Serving wastewater treatment plant
  - Remote part of site adjacent to wooded area
- Three options considered:
  - Capital replacement
  - Reprocess existing mineral oil
  - Retrofill with canola (rapeseed) based natural ester
- Service company recommended and delivered ester retrofill option
  - Met customer mandated risk reduction requirement
  - Less downtime
  - 50% cost saving over other options

Conclusions

Switching to ester filled transformers…

- REDUCES Fire Risk
- SAVES Money
- PROVEN solution

If prevention is better than cure, the further adoption of ester transformer liquids will benefit industrial users.

QUESTIONS?

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