FUCHS BluEV

High performance battery cooling by innovative immersion cooling systems

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Agenda

01 What drives BEV direct cooling

Market trends, technology drivers, battery immersion cooling

02 Challenges of immersion cooling dielectric fluids

Integration, efficiency, safety

03 Dielectric fluid development process

Formulation, simulation and testing

04 FUCHS BluEV technology promise

FUCHS BluEV integrated solution portfolio

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01 What drives BEV direct cooling

Market trends, technology drivers,
battery immersion cooling

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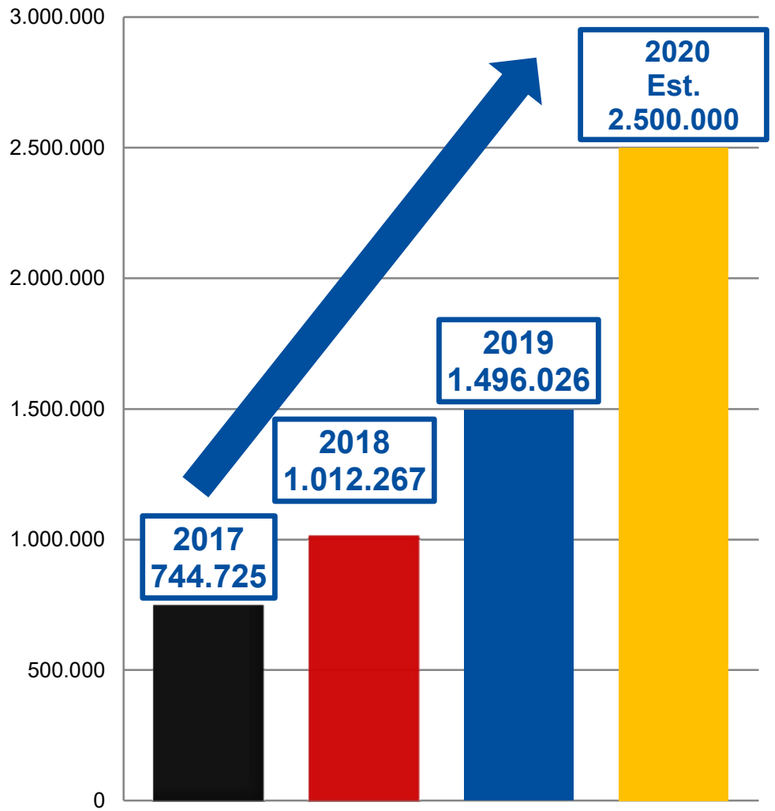
01 Market trends

xEV sales Europe + recent press releases



Source: ACEA

Electric cars to triple market share in Europe amid COVID-19, researchers say

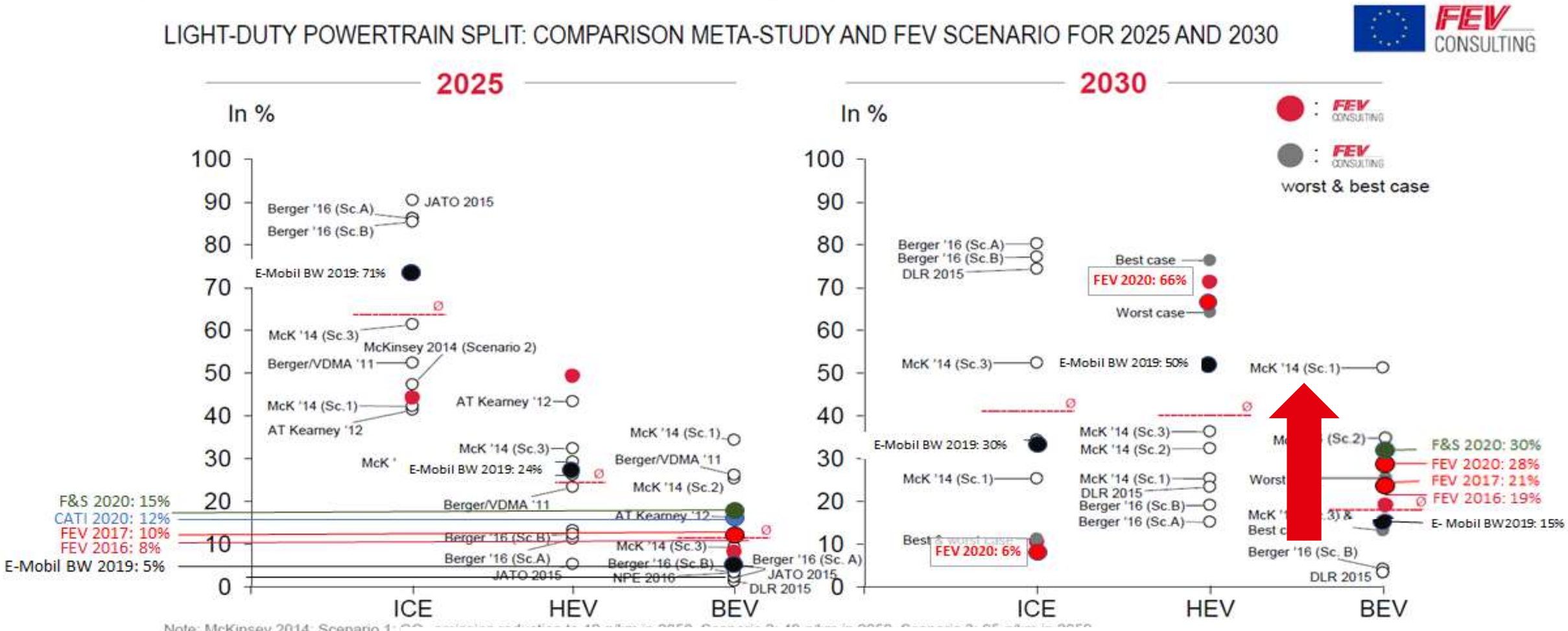
France Hits Record 19.2% EV Share In December — Up Almost 6× Year On Year

UK's EV Market Share Jumps To 16% In November — Overtaking Diesel

EV sales triple in Germany, disrupting market with 11% share

01 Market trends

Dynamics in published consulting agencies studies



Note: McKinsey 2014: Scenario 1: [illegible]
Roland Berger 2016: Scenario A: [illegible]

+ added information by FUCHS 2020

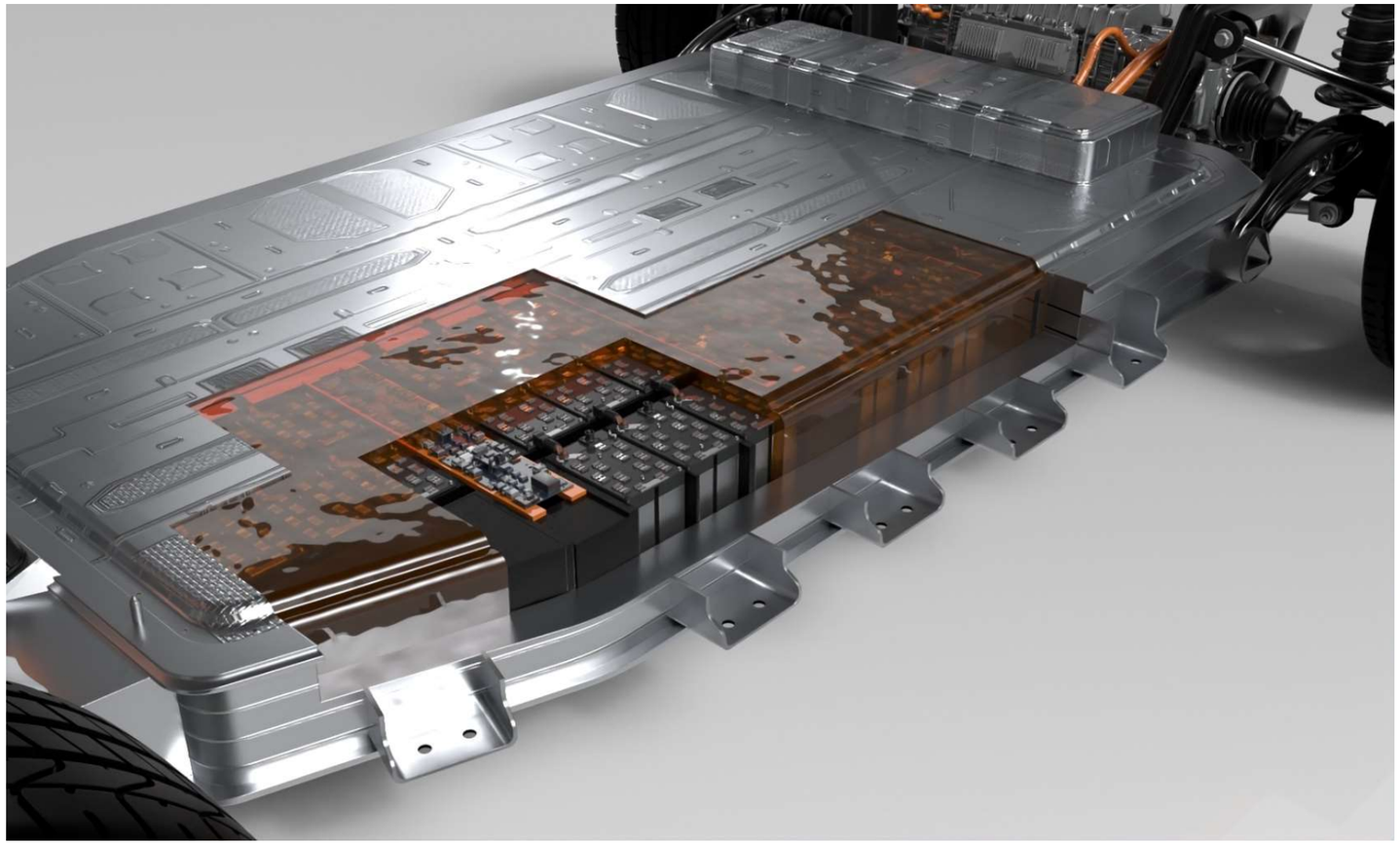
01 Technology driver
Ultra Fast Charging Challenge

- High energy density
- Up to 50kW dissipation loss!
- Safety optimization
- Maximum efficiency
- Condition monitoring requires homogeneous cell temperature

Source: Porsche AG, Taycan Turbo S

01 Battery Immersion Cooling
How and why?

- Battery immersed with cooling fluid
- Insulating dielectric fluid is derived from transformer fluid
- Highest heat transfer capability
- Homogeneous battery cell temperature
- Increased safety



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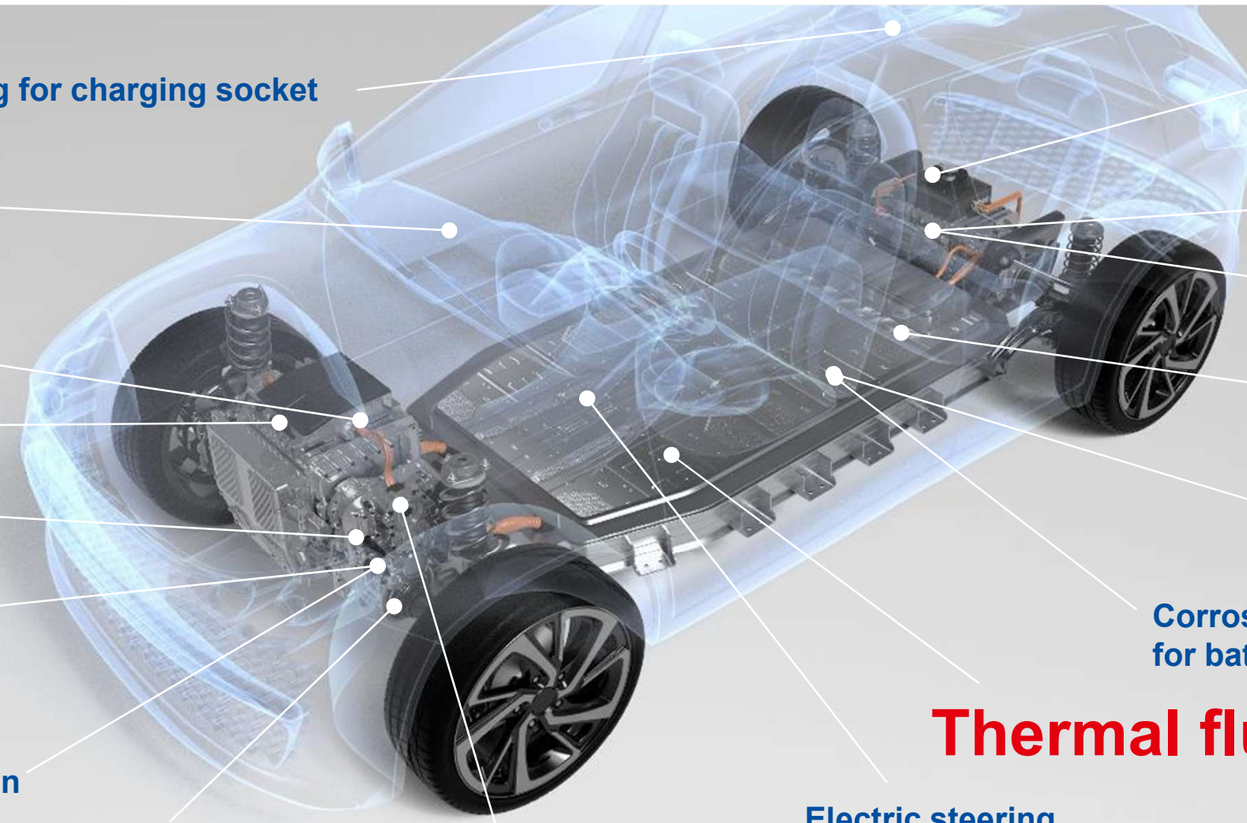
01 Battery immersion cooling
FUCHS BEV applications



Contact coating for charging socket

Noise cancelling in the interior

Contact grease and cleaners for electric connections

Thermal fluid for power electronics

Cutting oil for electrical sheets in E- Motor

Metal working fluids for production of E- Motor and transmission

E-Drive oil for E-Motor and transmission

E-Drive CV Joint grease

Compressor oil for heatpump / air condition

Electric steering greases

Low noise grease for ventilators and pumps

Drawing oils for copperwire

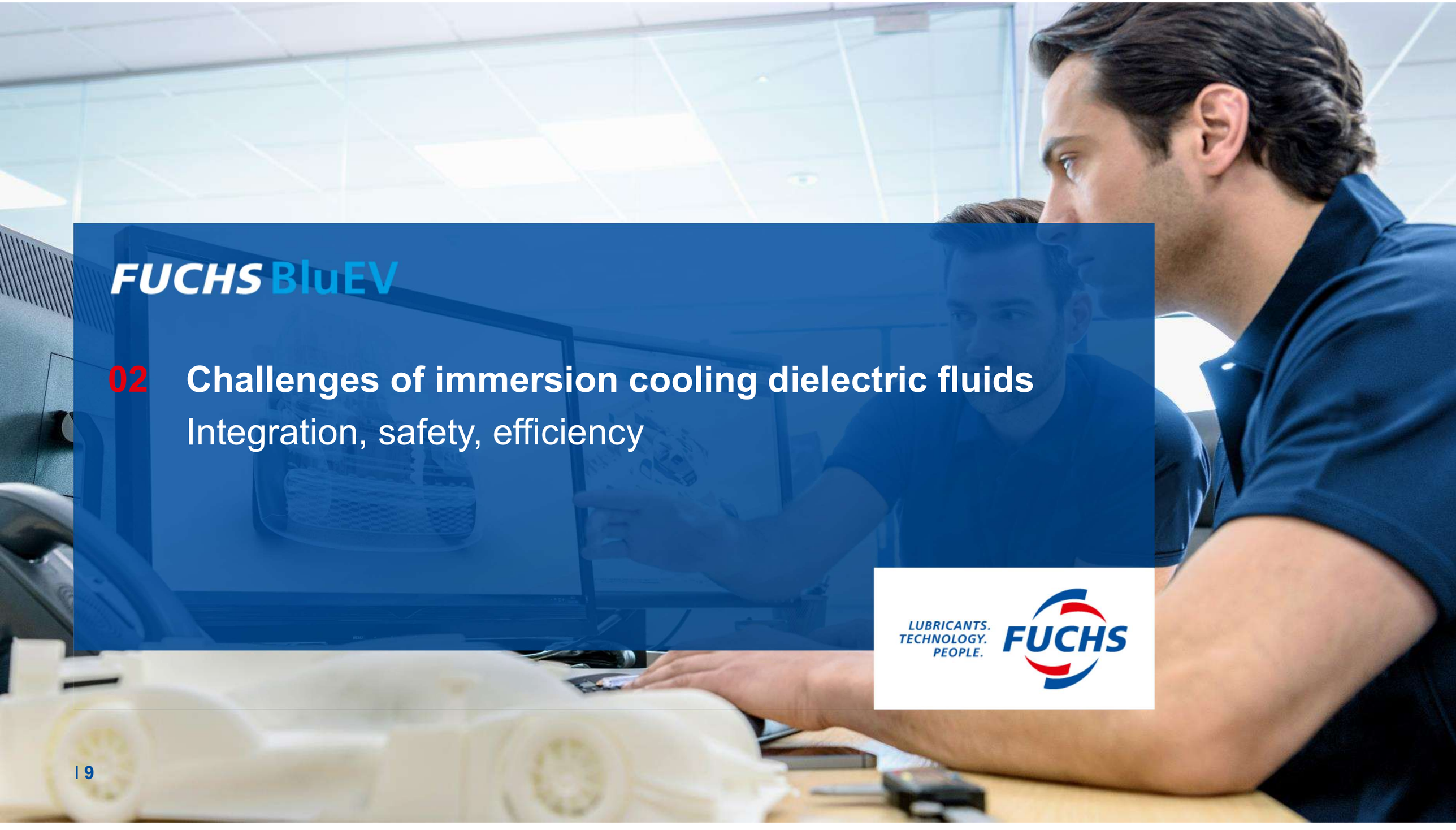
Bearing and sealing greases for E-Motors

Cleaners in battery production processes

Forming oils for battery cell cups or battery cases

Corrosion protection for battery housing

Thermal fluid for battery



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02 Challenges of immersion cooling dielectric fluids

Integration, safety, efficiency

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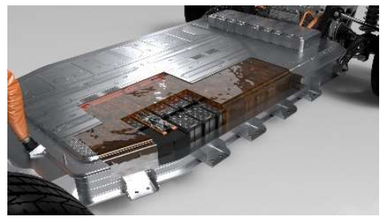
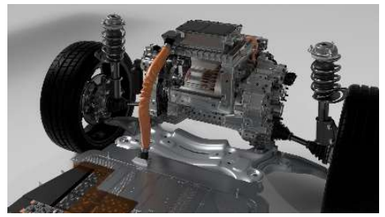
02 Integration

Multiple temperature levels in BEV components

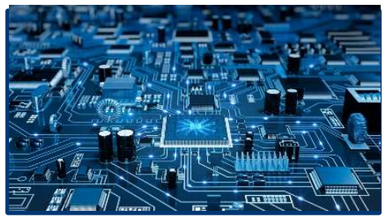


Battery



Powertrain Electronics & E-Motor

Cabin



On- board electronics

Key challenges

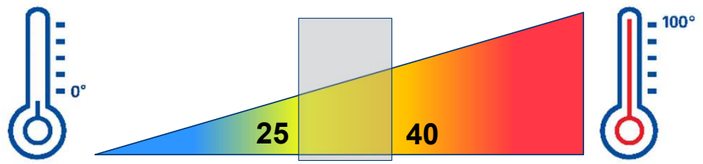
- Thermal management for performance and lifetime
- Heating and cooling

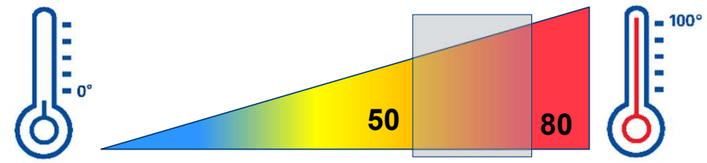
- Cooling only
- High gradients, intermittent

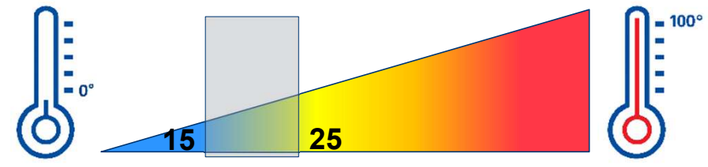
- Cooling and heating
- ICE waste heat non existent

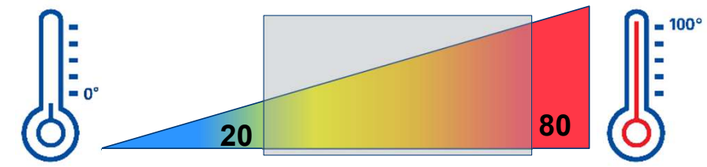
- Cooling only
- Hotspots

Operating temp (°C)



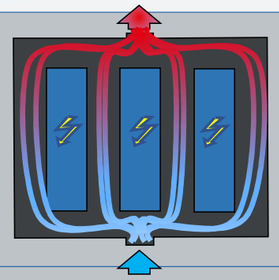
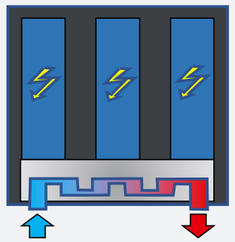
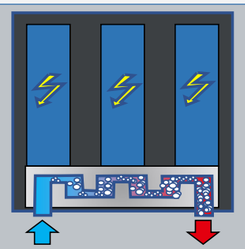
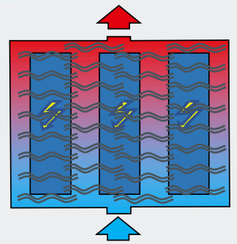






02 Integration

Battery thermal management solutions

Type	Air	Water-Glycol	Refrigerants	Dielectric Fluids
				
Description	Direct cooling Forced convection by airflow around cells	Indirect cooling through pipe and heat exchanger system	Indirect cooling by expansion of refrigerant in heat exchanger system	Direct cooling forced convection by fluid flow around cells
Advantages	Low cost of system	Fluid already available at car production sites Low cost of fluid	High heat transfer rates	No additional heat exchanger system inside battery needed Higher energy density Highest efficiency and cooling capability
Disadvantages	Low specific heat capacity of air = low efficiency Loud High space demands	Conductive fluid in high voltage environment needs higher safety efforts Smaller contact surface to cells = low efficiency	High Power and high pressures required Only cooling, separate heating system required	Fluid either environmentally harmful, expensive and heavy or flammable Higher fluid volume

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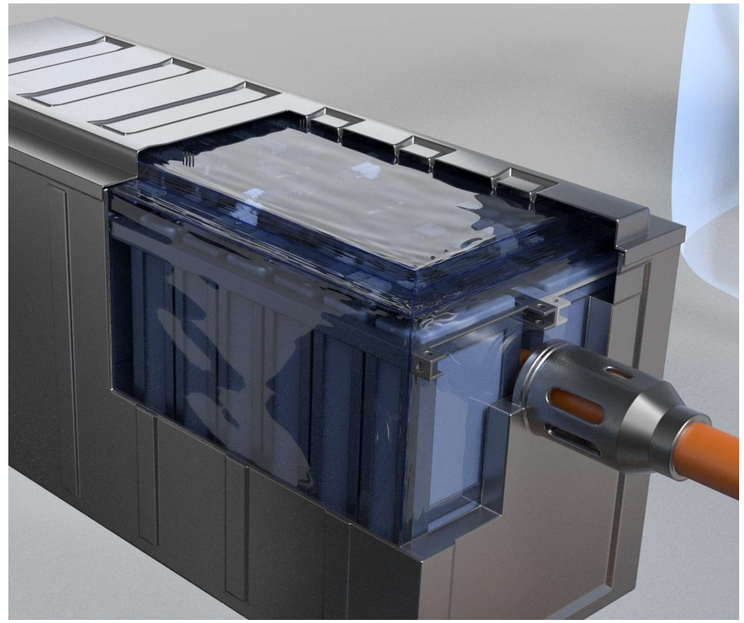
02 Integration

Thermal management media for direct cooling of batteries

Coolant	Direct cooling	Cost	Energy efficiency	Heat transfer	Electrical conductivity	Fire resistance	Weight	Ecology
Water / Glycol	X	++	++	++	- -	+	-	++
Hydro Fluoro Ethers		- -	+	+	++	++	- -	- -
Heat Transfer Oils		+	--	+	+	-	+	+
Transformer Oils		+	-	+	++	o	+	+
Dielectric Thermal Fluids, designed for Batteries		+	+	+	++	o	+	+

02 Safety

- Low flammability
- Robust and homogeneous cooling, no thermal peaks
- Effective cooling results in less risk of thermal runaway
- New China GB/T standard 38031 for BEV safety



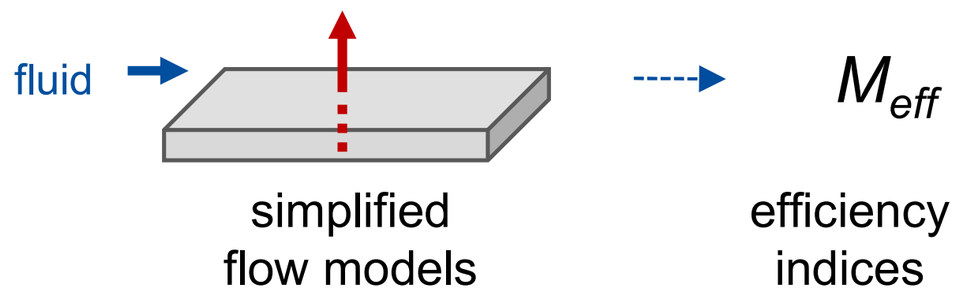
02 Efficiency

Heat transfer Comparison of thermal fluids using efficiency indices

Thermal fluid
- thermal conductivity
- heat capacity
- density
- viscosity

System and operation
- design, geometry, operation parameters
- cooling surface area A
- temperature difference ΔT
- flow regime (laminar/turbulent)
- forced convection / 2-phase
- materials, surfaces, coatings, …

$$\dot{Q} = \alpha \cdot A \cdot \Delta T$$



Efficiency is influenced by a combination of caloric and hydraulic fluid characteristics

02 Efficiency

Heat transfer models laminar and turbulent flow

$$M = \frac{\rho^a \cdot \lambda^b \cdot {C_p}^c}{\mu^d}$$

M efficiency index*

ρ density
λ heat conductivity
C_P specific heat capacity
μ dynamic viscosity

$$M_1 = \frac{\rho^{0.33} \cdot \lambda^{0.67} \cdot {C_p}^{0.33}}{\mu^{0.17}}$$

- simple model
- laminar flow
- pump energy neglected

$$M_2 = \frac{\rho^{0.40} \cdot \lambda^{0.20} \cdot {C_p}^{0.40}}{\mu^{0.20}}$$

- **advanced model [1]**
- **laminar flow**

Immersion battery cooling

$$M_3 = \frac{\rho^{0.80} \cdot \lambda^{0.67} \cdot {C_p}^{0.33}}{\mu^{0.47}}$$

- advanced model [2]
- turbulent flow

* also described as Mouromtseff number

1 D.B. Tuckerman: Heat-Transfer Microstructures for Integrated Circuits, 1984
2 R.E. Simons: Comparing Heat Transfer Rates of Liquid Coolants, 2006

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03 Dielectric fluid development process

Formulation, simulation and testing

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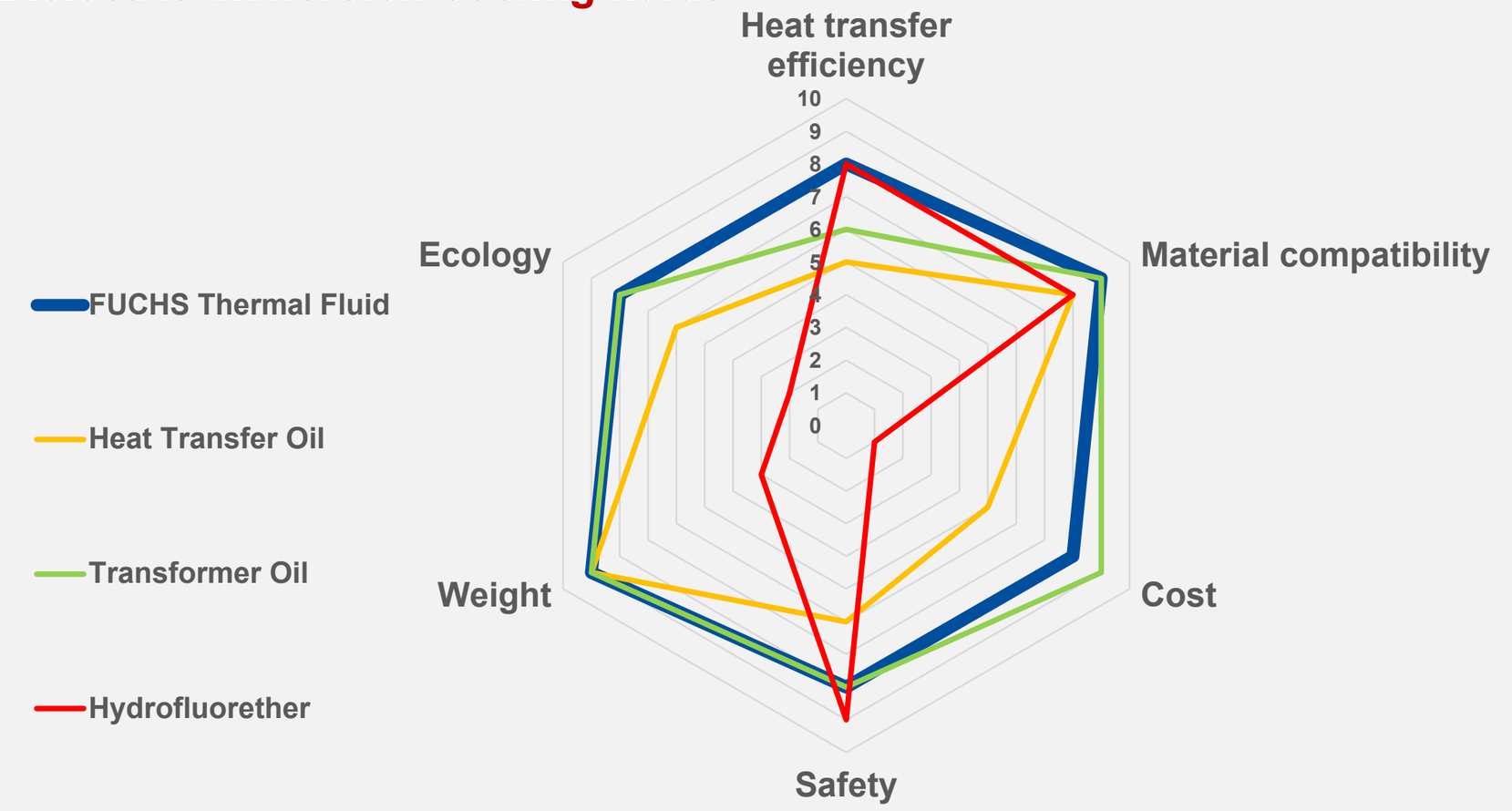
03 Formulation

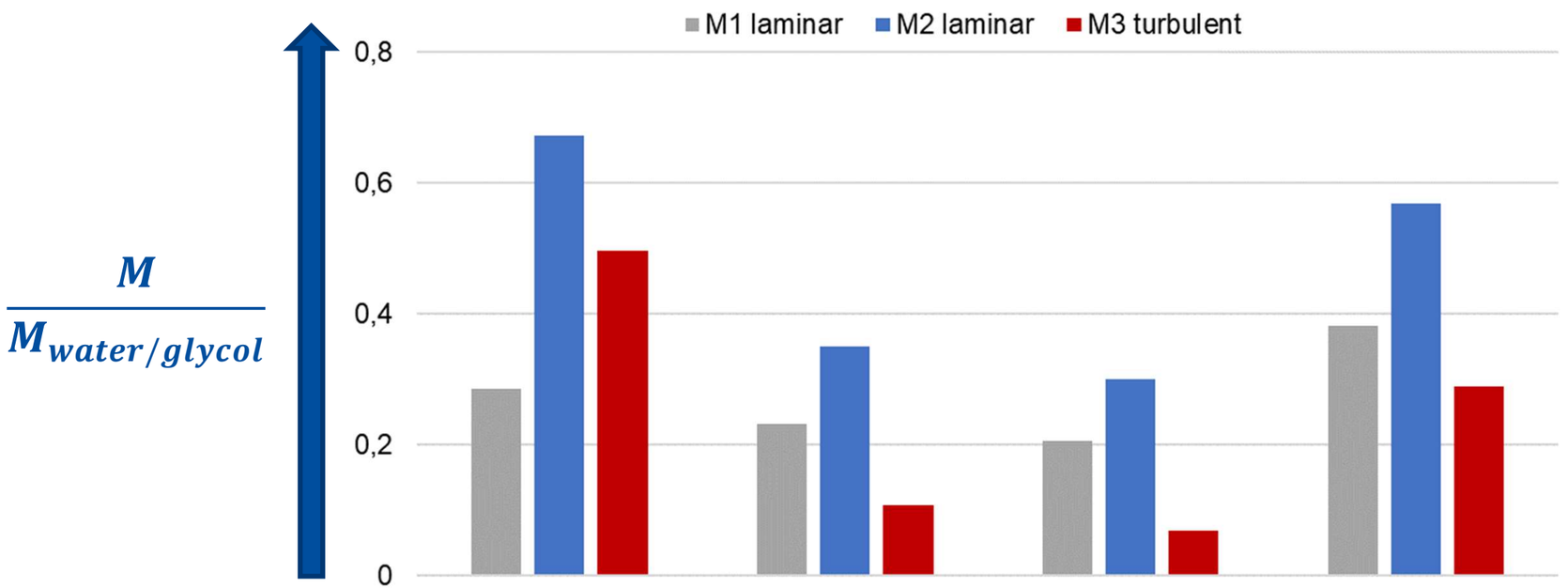
Hydrocarbon based dielectric fluids offer best overall performance

Dielectric Immersion cooling fluids



03 Formulation

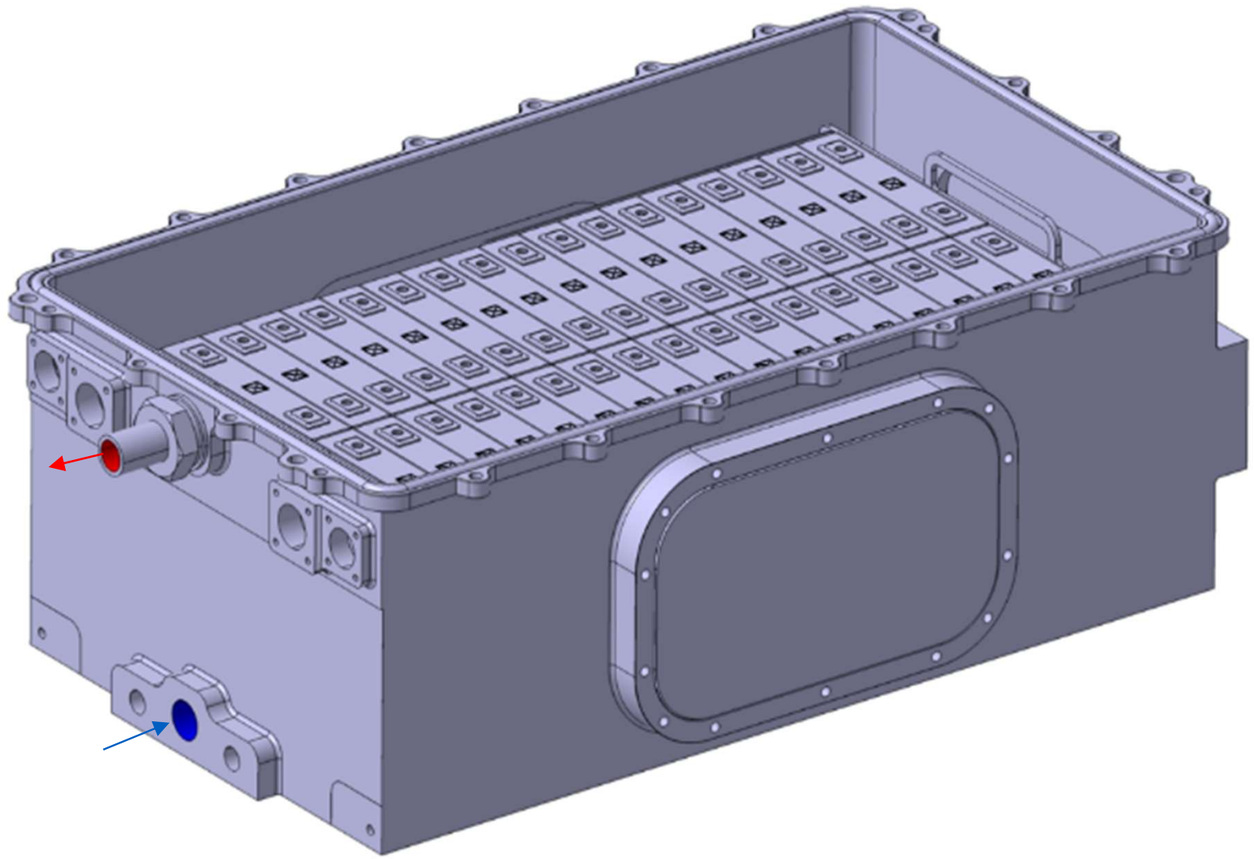
Products made to measure: Comparison of thermal fluids



Properties	Hydrofluoroether	Aromatic heat transfer oil	Mineral heat transfer oil	FUCHS dielectric fluid
Kin viscosity 40°C / mm^2/s	-	16,5	44	5
Density 20°C / kg/m^3	1,618	1,044	0,870	0,808
Thermal conductivity 20°C / W/(m*K)	0,065	0,131	0,133	0,154
Specific heat capacity 20°C / kJ/(kg*K)	1,129	1,6	1,88	2,1

03 Testing
Comparison of thermal fluid formulation strategies

- **Hermetic module casing**
- **Battery cells immersed in dielectric liquid**
- **Circulating cooling liquid, controlled in temperature / flow / pressure**
- **Specific flow pattern around battery cells, flow channels arranged in parallel**



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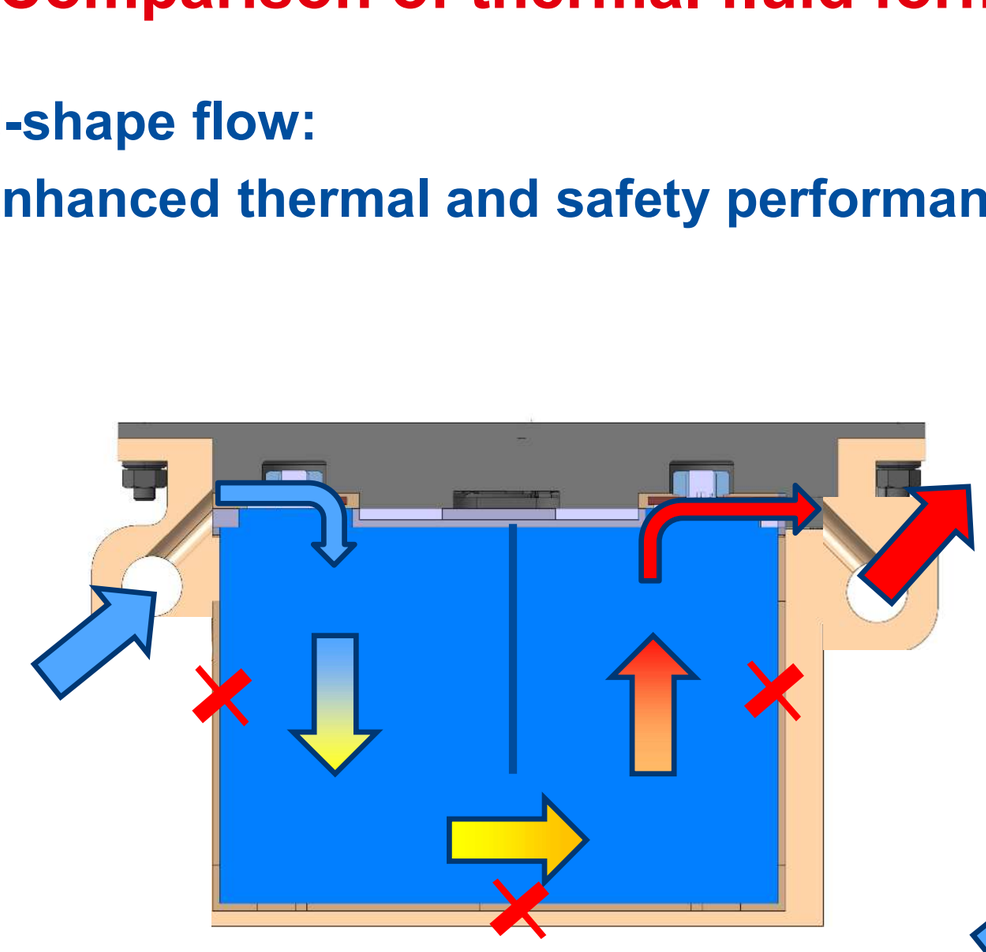
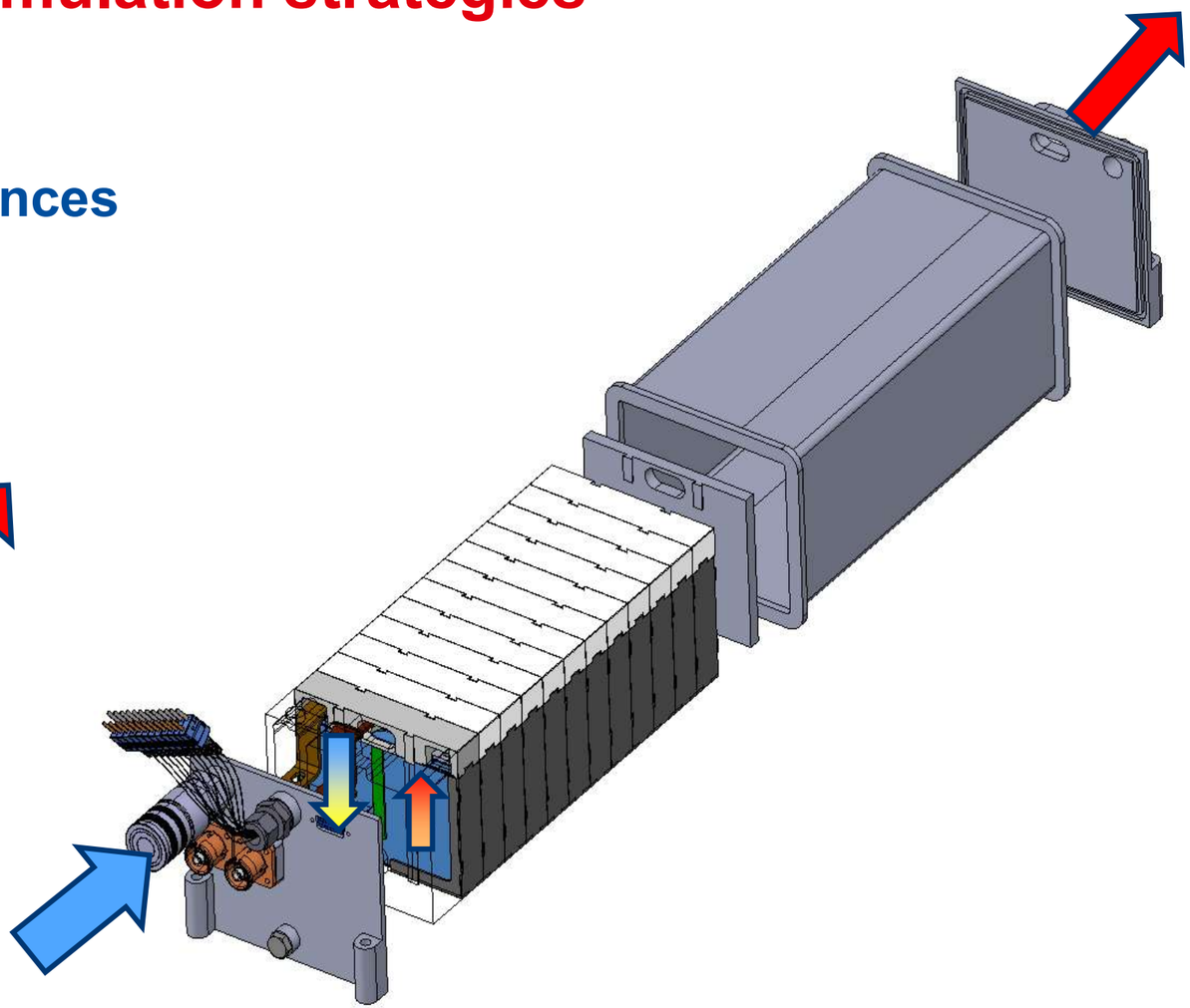
03 Testing
Comparison of thermal fluid formulation strategies

- U-shape flow:
- Enhanced thermal and safety performances





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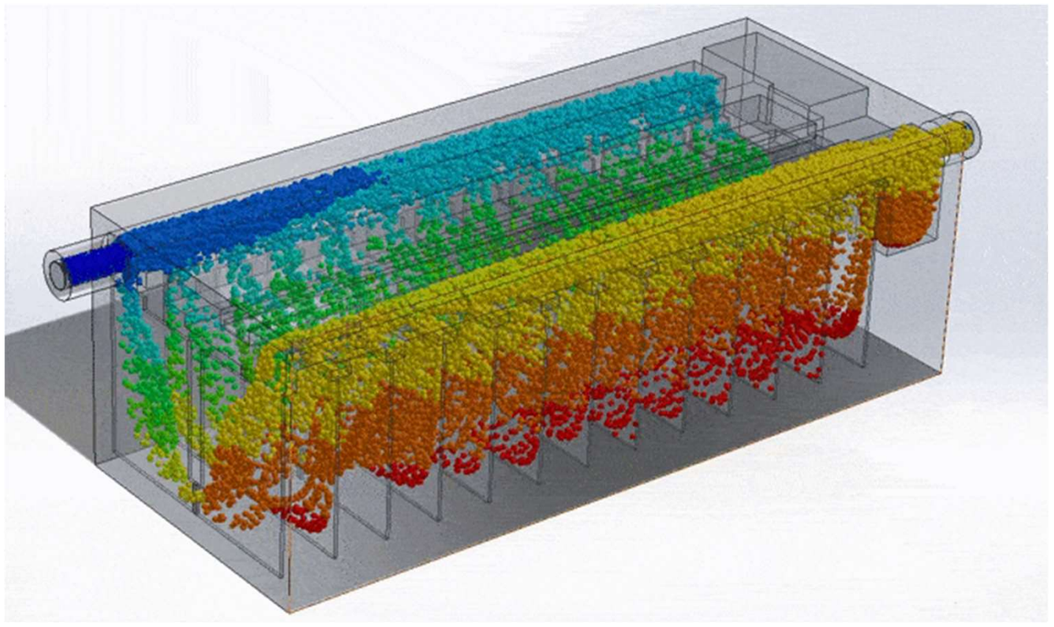
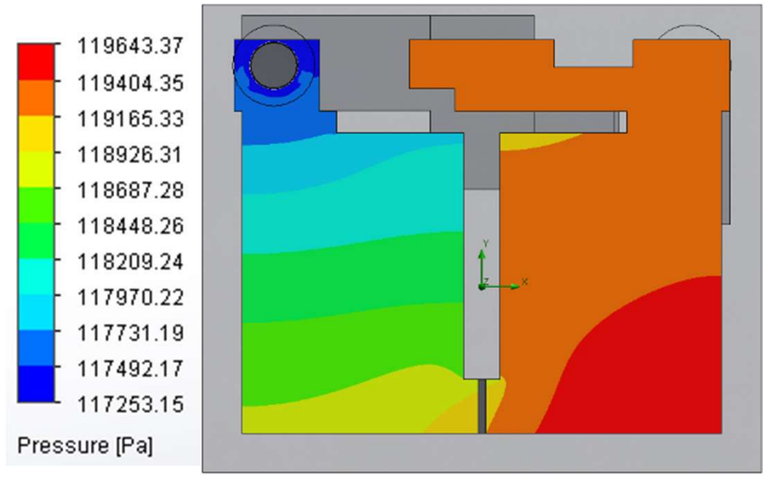
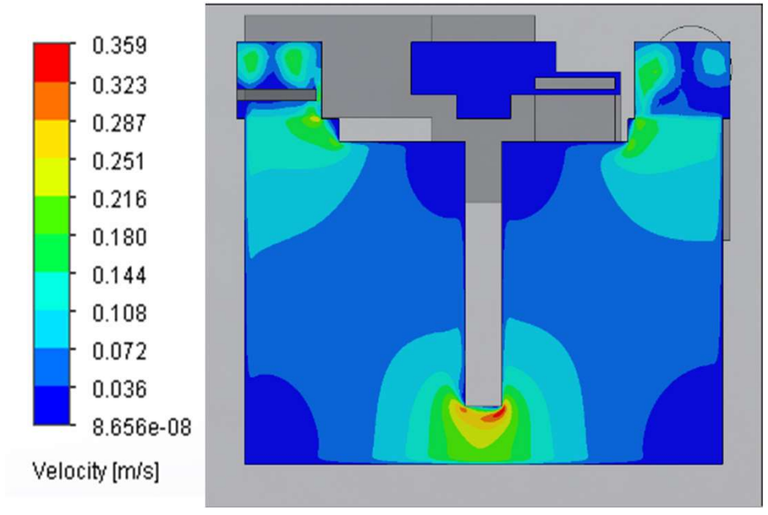
03 Simulation

Comparison of thermal fluid formulation strategies

- Flow simulation that combining heating and flow calculation
- Speeds and pressure pattern of the flow in-between prismatic cells in immersion cooling







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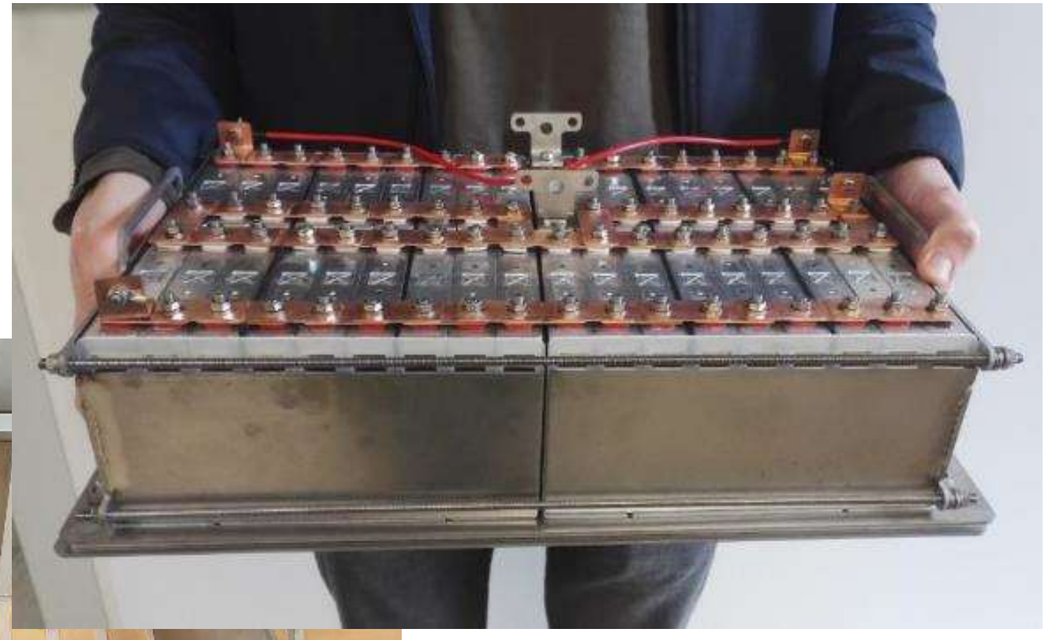
03 Testing
Comparison of thermal fluid formulation strategies

- EXOES designed a module made of dummy cells
- 1x actual LTO cell (Toshiba SCiB 10Ah)
- Surrounded by 35x dummy heating cells
- 26x temperature sensors enclosed



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03 Formulation

Testing: Material compatibility (Construction polymers, sealants)

Construction polymers (examples) acc. to ASTM D3455	Sealants (examples) acc. to ISO 1817: 2015-02	Tested properties (examples)
Polycarbonate (PC)	Fluorocarbon rubber (FKM)	Shore D hardness / Ball intendation hardness
Polyphenylene sulfide (PPS)	Alkyl acrylate copolymer (ACM)	Strength
Polyamide - Polycaprolactam (PA6)	Hydrogenated acrylonitrile butadiene rubber (HNBR)	Strain at strength
Polybutylene terephthalate/ Acrylonitrile styrene acrylate (PBT/ASA)	Ethylene acrylic rubber (AEM)	Stress at break
		Strain at break

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04 FUCHS global footprint

Covering all applications and regions

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04 FUCHS global footprint
Covering all applications and regions

Stefan Fuchs, Chairman of the Board

» We have relied on **continuity, reliability and proximity** – for more than 85 years.«

04 FUCHS global footprint
FUCHS PETROLUB SE at a glance

Established 3 generations ago as a family-owned business

No. 1 among the independent suppliers of lubricants

Approx. **€2.6** bn sales in 2018

The Fuchs family holds **55%** of ordinary shares

A full range of over **10,000** lubricants and related specialties

More than **5,400** employees

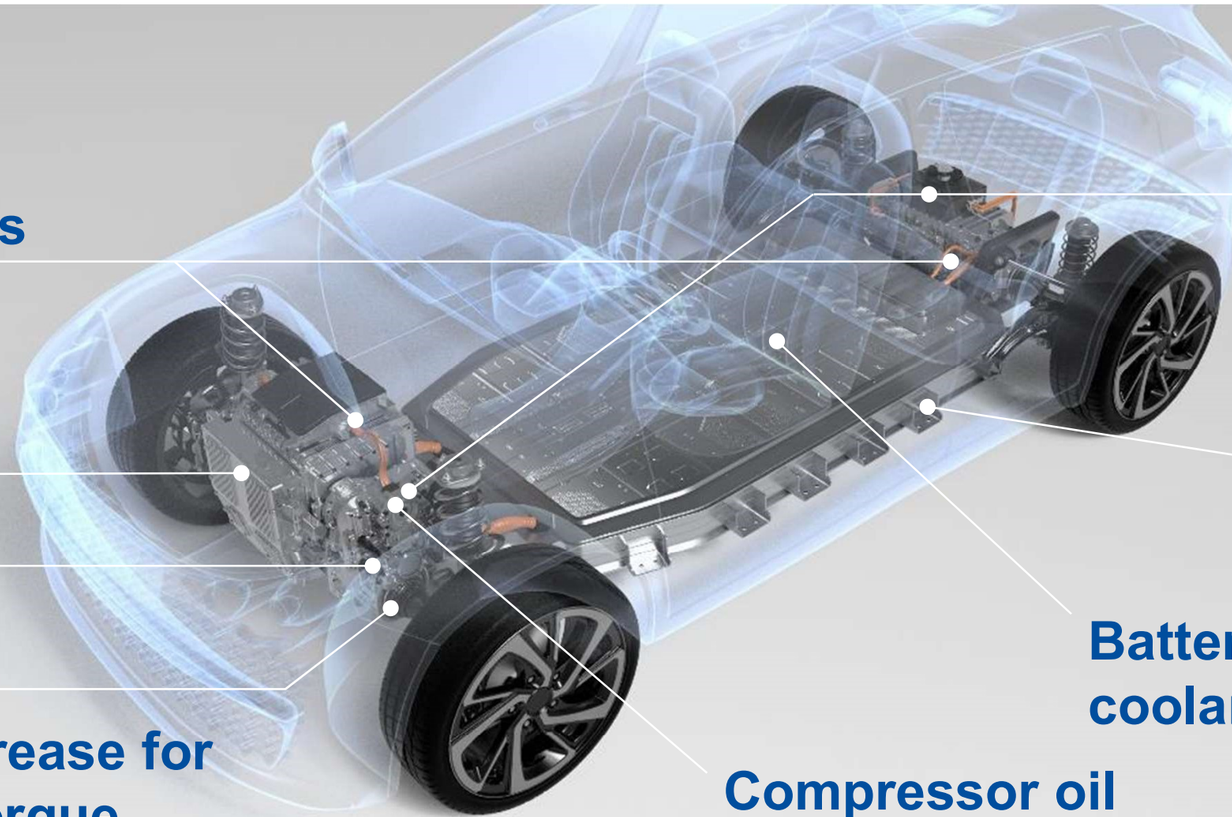
Preference share is listed in the MDAX

58 companies worldwide

01 FUCHS BluEV product line
Customized 360-degree solutions

04 FUCHS global footprint

Covering all applications: BEV product portfolio



Contact grease for electric connections

Grease for E-Motor

Coolant for power electronics

Corrosion inhibitor for battery housing

E-Drive oil for E-Motor and gearbox

Battery coolant

Axle grease for high torque

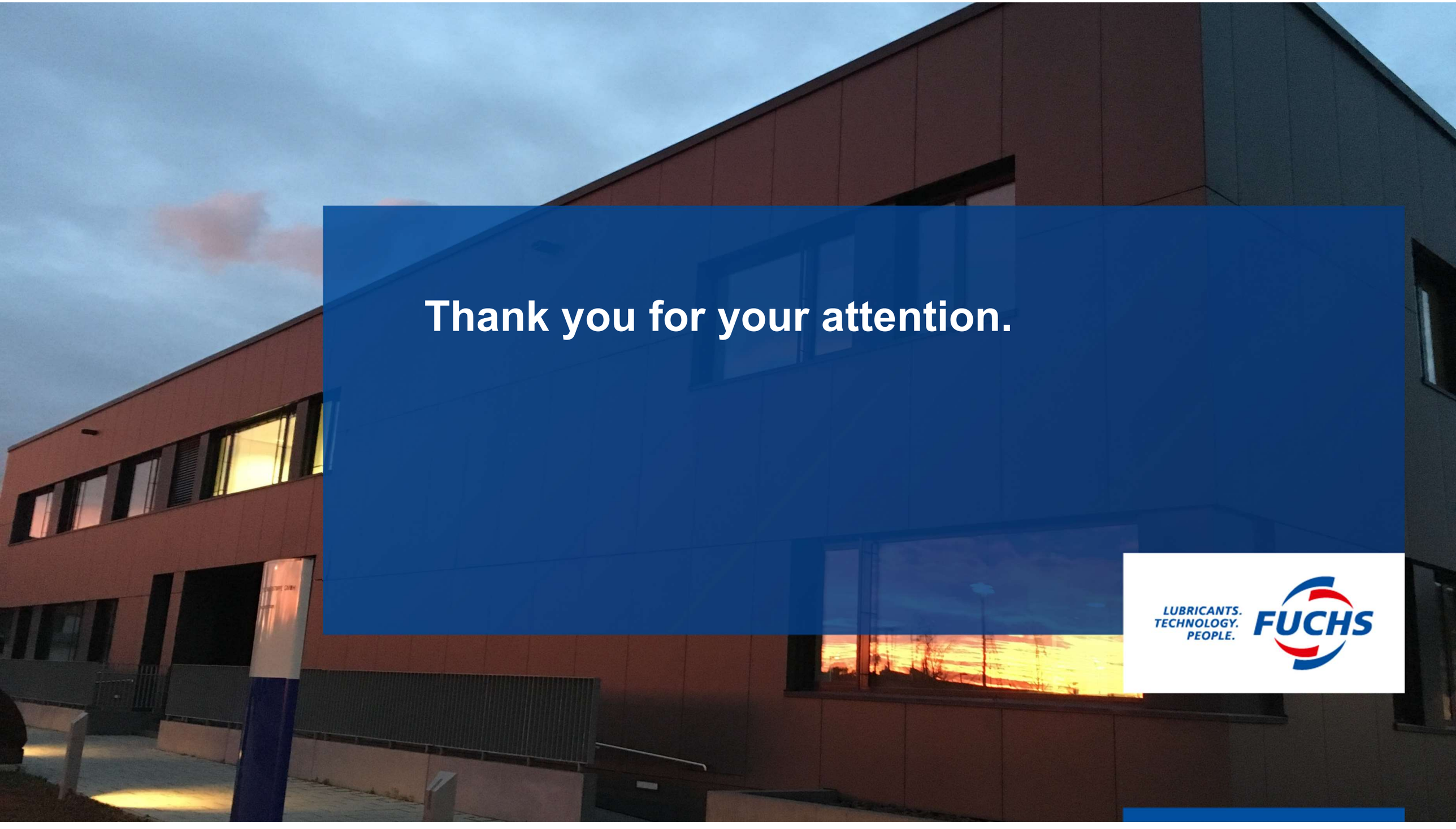
Compressor oil for heat pump / air condition

Products, which are needed independently from propulsion method are not shown

04 FUCHS global footprint

Covering all applications: HYBRID product portfolio

Products, which are needed independently from propulsion method are not shown



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