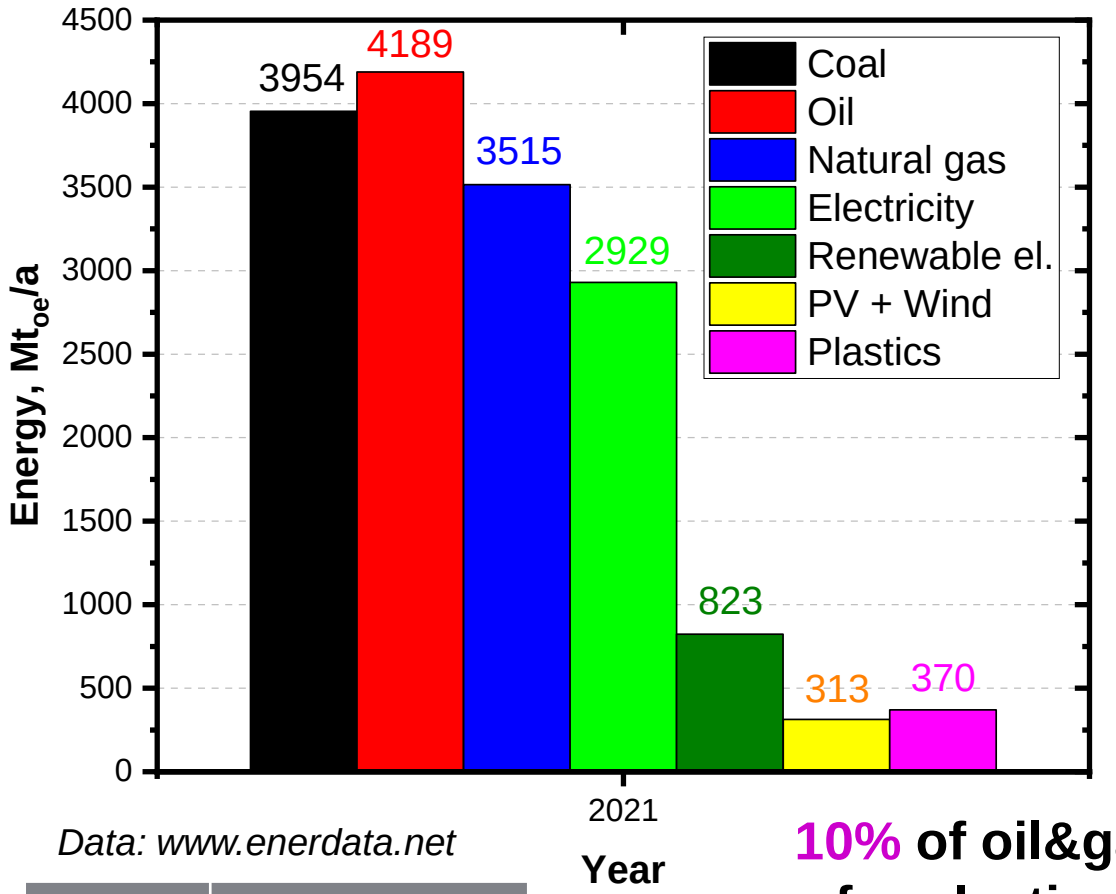
Symposium 2023
Linz, Austria
19. September 2023

ENERGIZING POLYMERS – TAILOR-MADE PLASTICS FOR RENEWABLE ENERGY TECHNOLOGIES

Gernot M. WALLNER

THE CURRENT ENERGY SYSTEM

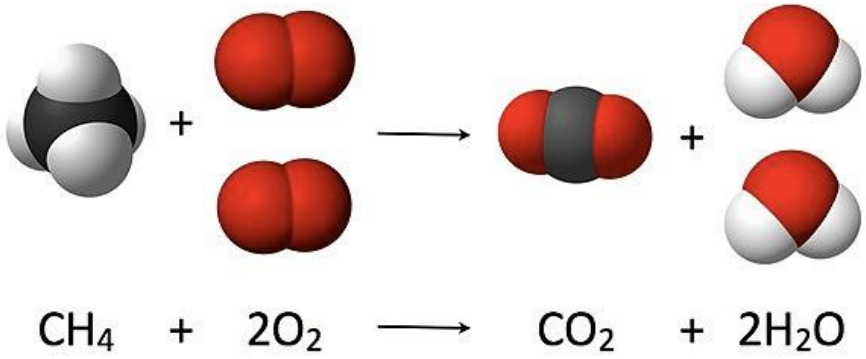


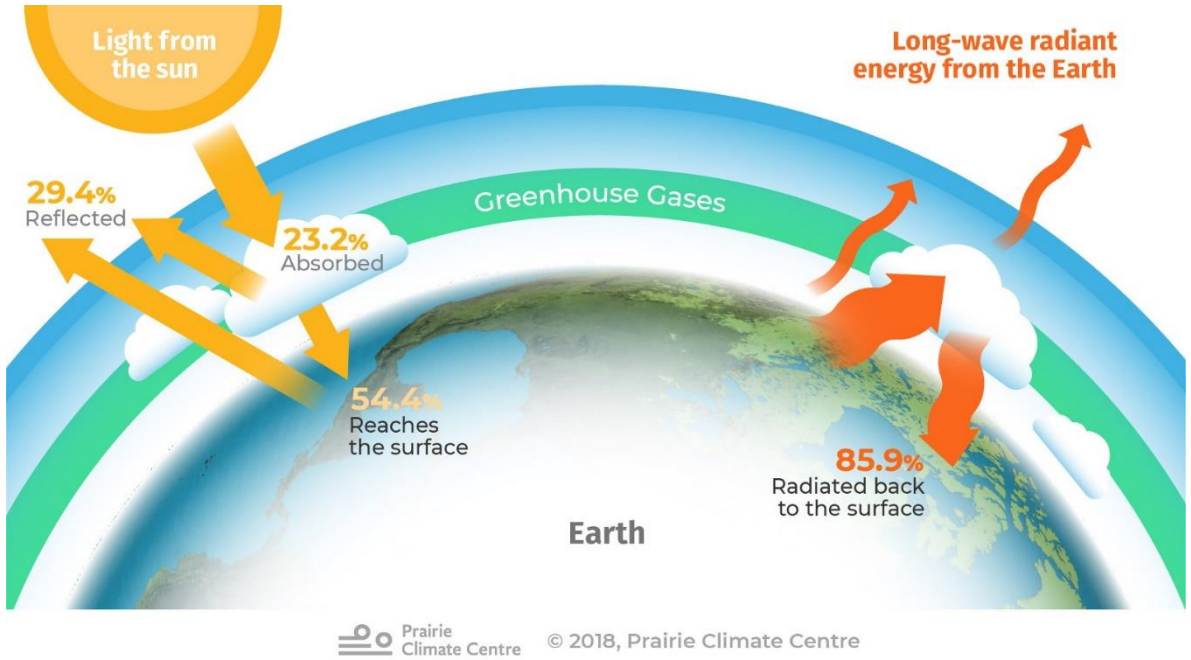
Data: www.enerdata.net

Year	Fossils, Bt_{oe}
1995	7,4
2021	11,7

10% of oil&gas for plastics

~ 42 Bt/a of CO_2 emissions



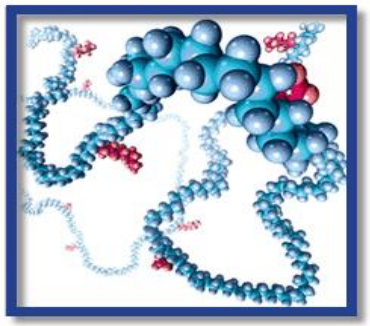


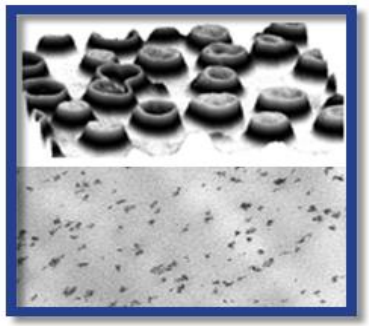
SOLAR THERMAL TECHNOLOGIES

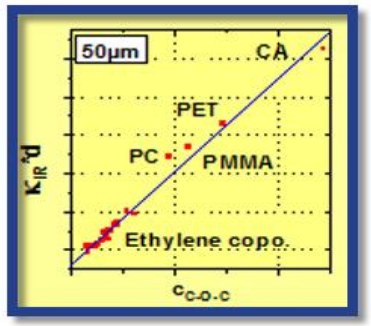
iPMT Institute of Polymeric Materials and Testing

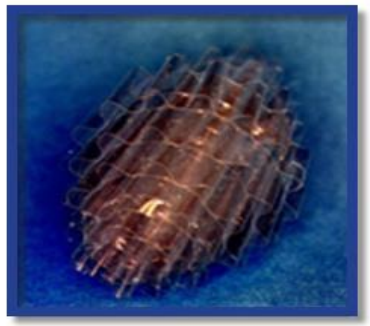
Molecular Structure	*Material Structure*	*Material Properties*	*Processing & Design*	*Aim: Service Performance*

Service Life



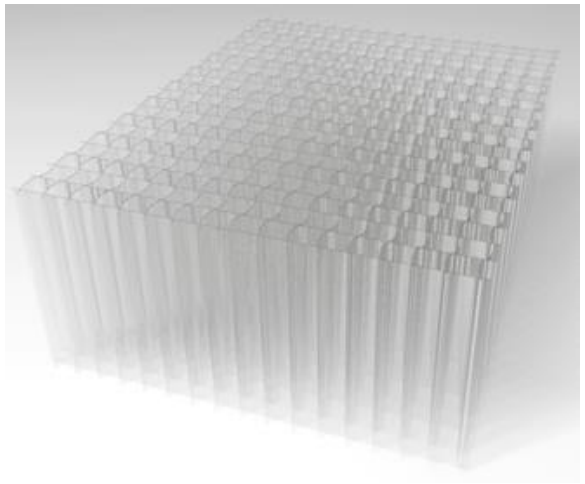


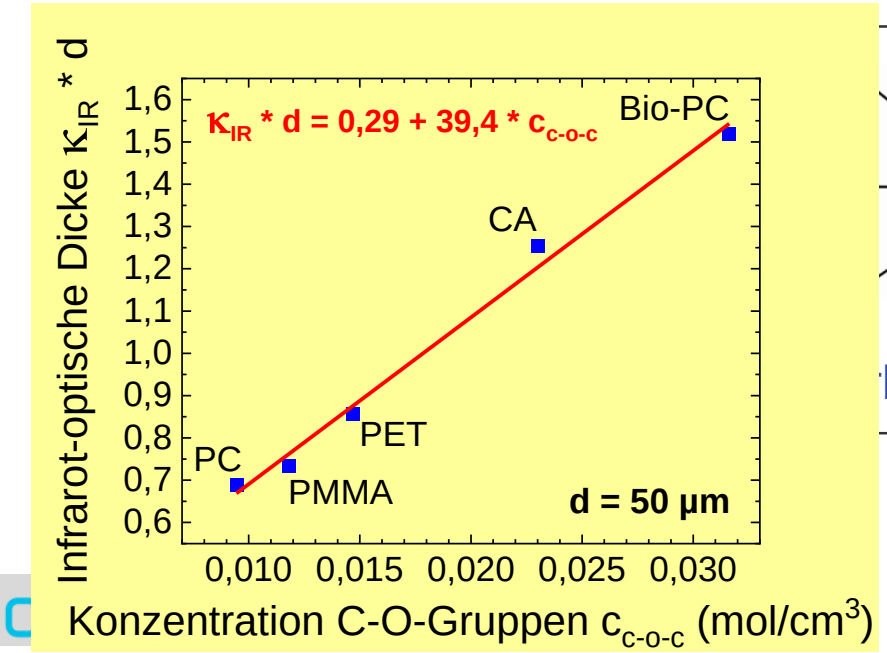


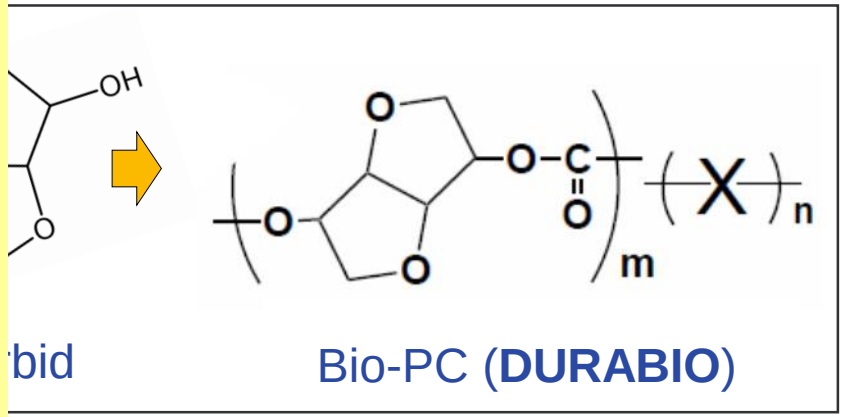


> 25 years

Key: Service oriented, accelerated lab test methodologies







Commerzialisation: unaco

Master thesis, J. Segsulka, 2023

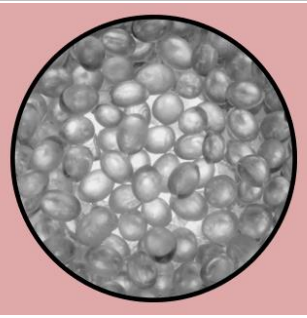
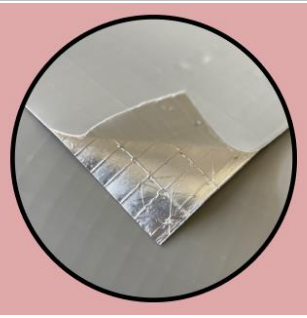
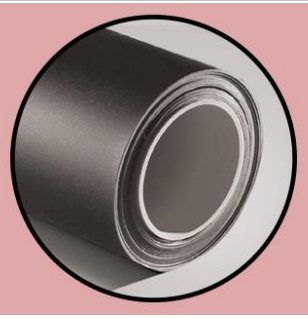
solpol

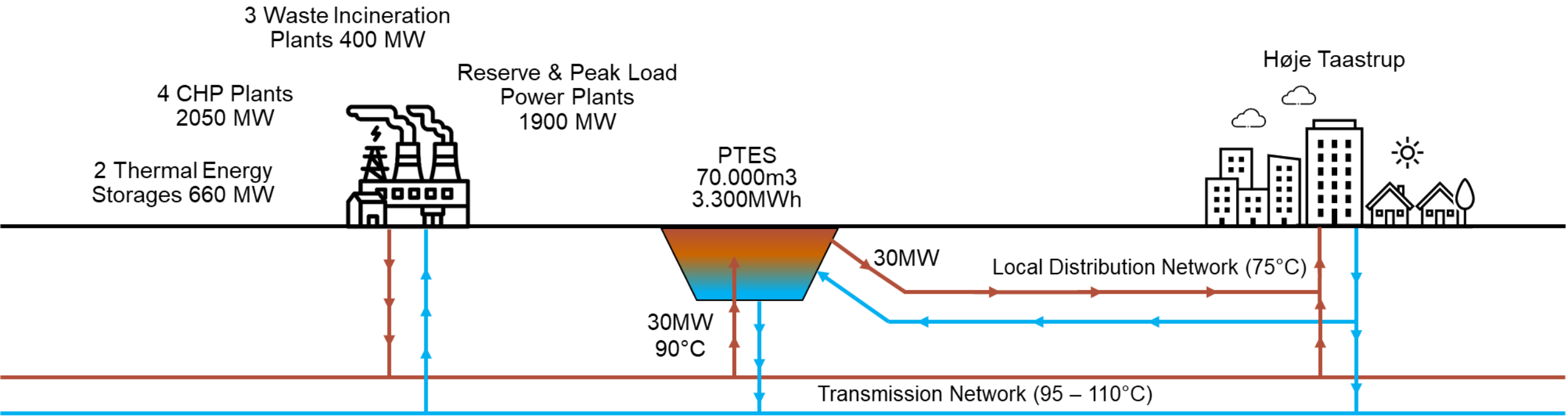
THERMAL ENERGY TECHNOLOGIES – GIGA-SCALE STORAGES

ipmt Institute of Polymeric Materials and Testing

solpol

gigaTES
www.gigates.at

	Rohstoff	Halbzeug	Komponente
AP-3: *PO-TES*	JKU-IPMT  Gabriel Chemie	JKU-IPMT  Lenzing Plastics	AEE INTEC  AGRU



THERMAL ENERGY TECHNOLOGIES – GIGA-SCALE STORAGES

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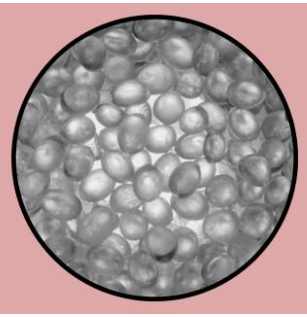
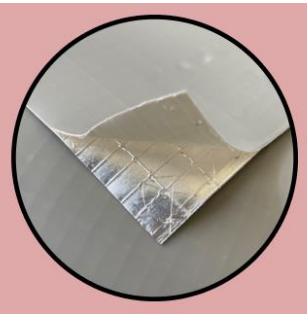
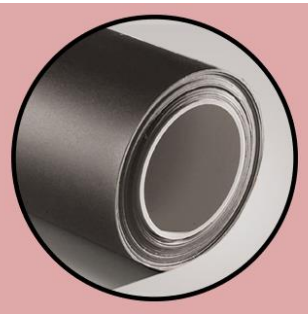
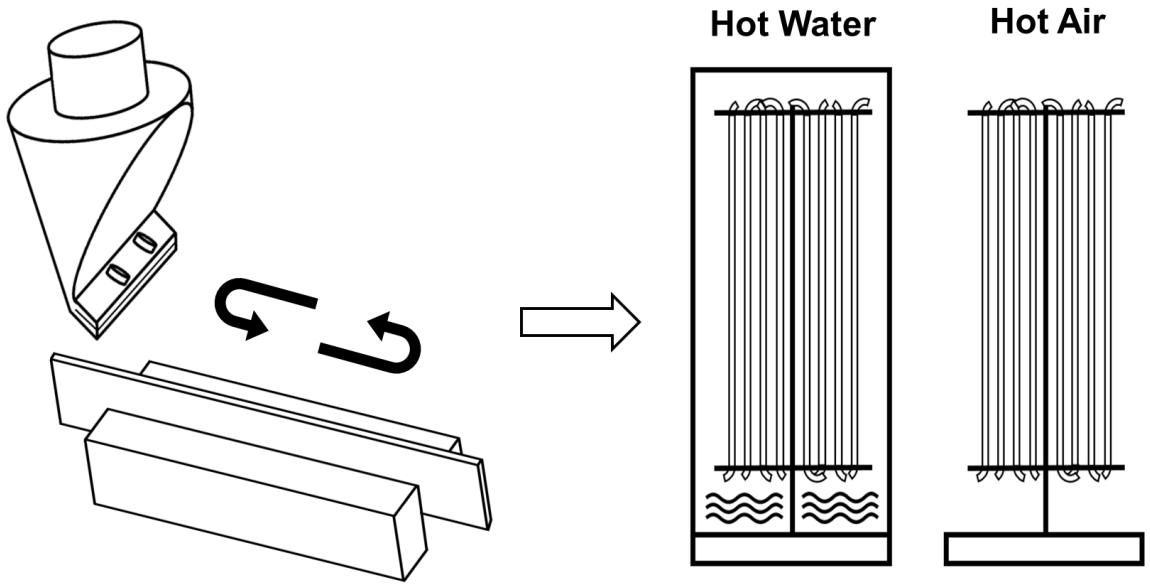
AP-3: *PO-TES*	JKU-IPMT  Gabriel Chemie	JKU-IPMT  Lenzing Plastics	AEE INTEC  AGRU



THERMAL ENERGY TECHNOLOGIES – GIGA-SCALE STORAGES

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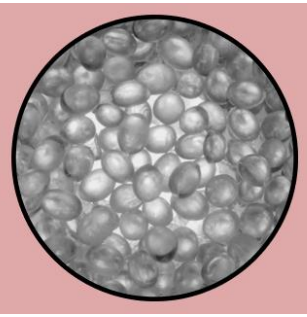
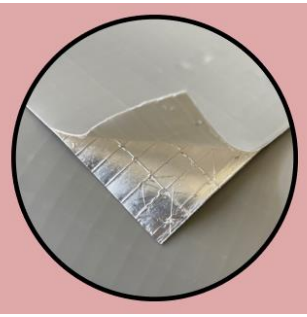
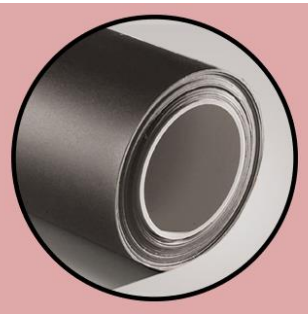
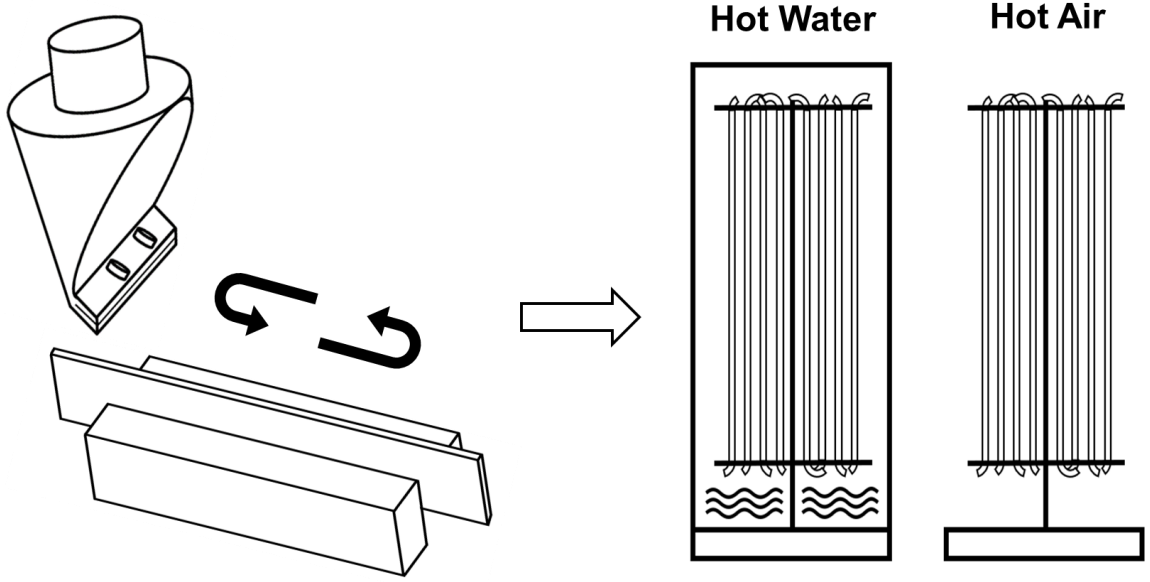
AP-3: *PO-TES*	JKU-IPMT  Gabriel Chemie	JKU-IPMT  Lenzing Plastics	AEE INTEC  AGRU



THERMAL ENERGY TECHNOLOGIES – GIGA-SCALE STORAGES

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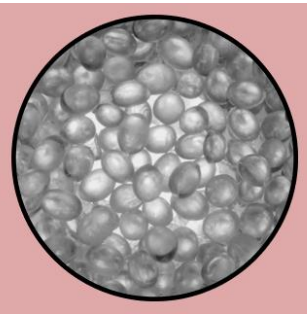
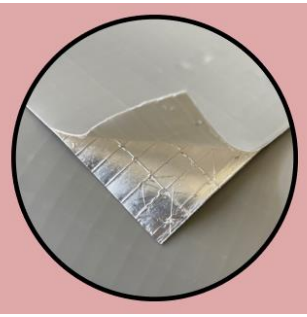
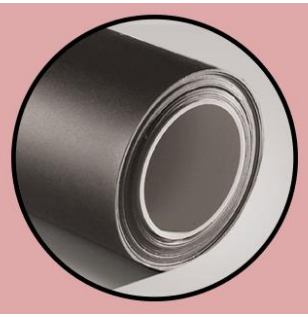
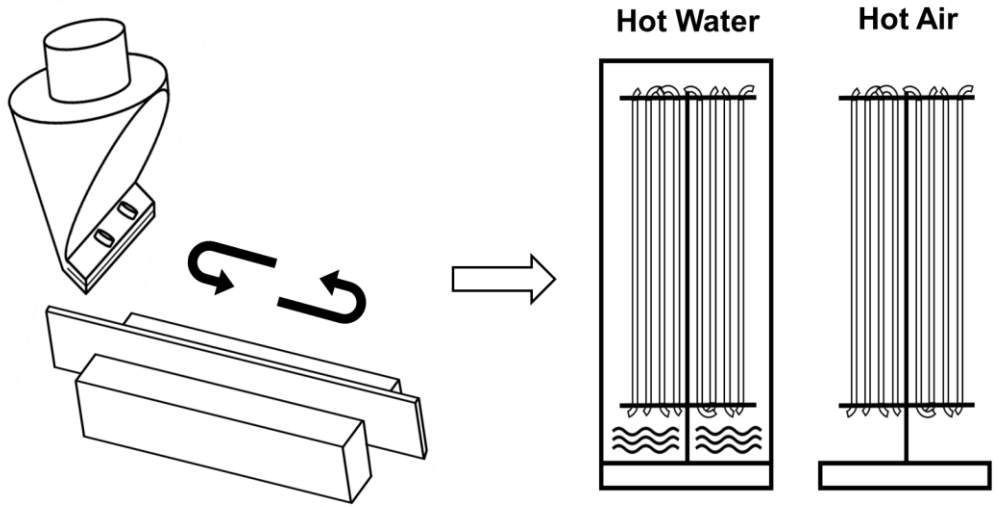
AP-3: *PO-TES*	JKU-IPMT  Gabriel Chemie	JKU-IPMT  Lenzing Plastics	AEE INTEC  AGRU



Commerzialisation:

High temperature resistant PP liners

Installation June 2021

PhD theses,
K. Grabmayer (2014),
M. Grabmann (2018),
L. Peham (ongoing)

1st commercial seasonal storage with PP-liner (Høje Taastrup, DK)

THERMAL ENERGY TECHNOLOGIES – GIGA-SCALE STORAGES

PLASTICS & RENEWABLE ELECTRICITY

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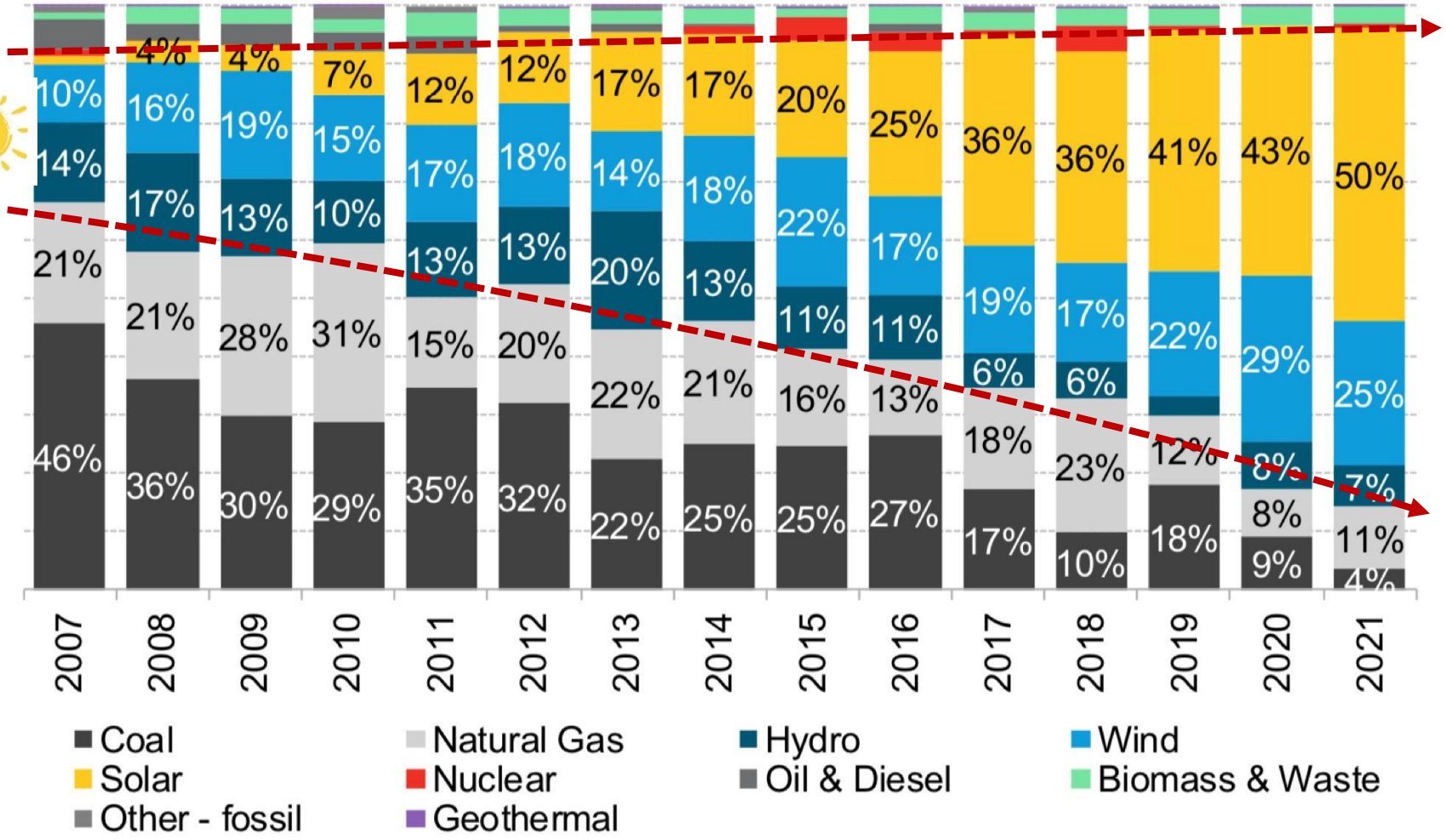
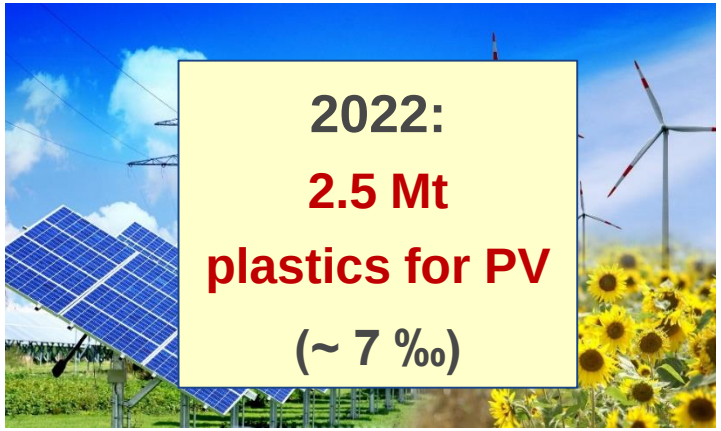
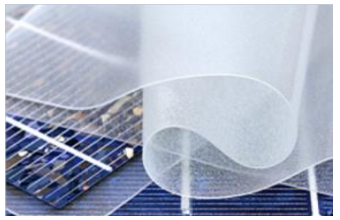
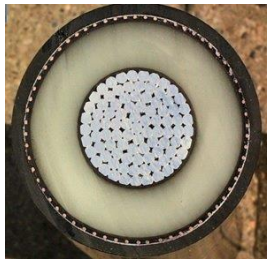


Source: BloombergNEF. Note: Share of global capacity additions excluding retirements.







Plastics enable solar electricity!

PLASTICS INDUSTRY & PHOTOVOLTAICS

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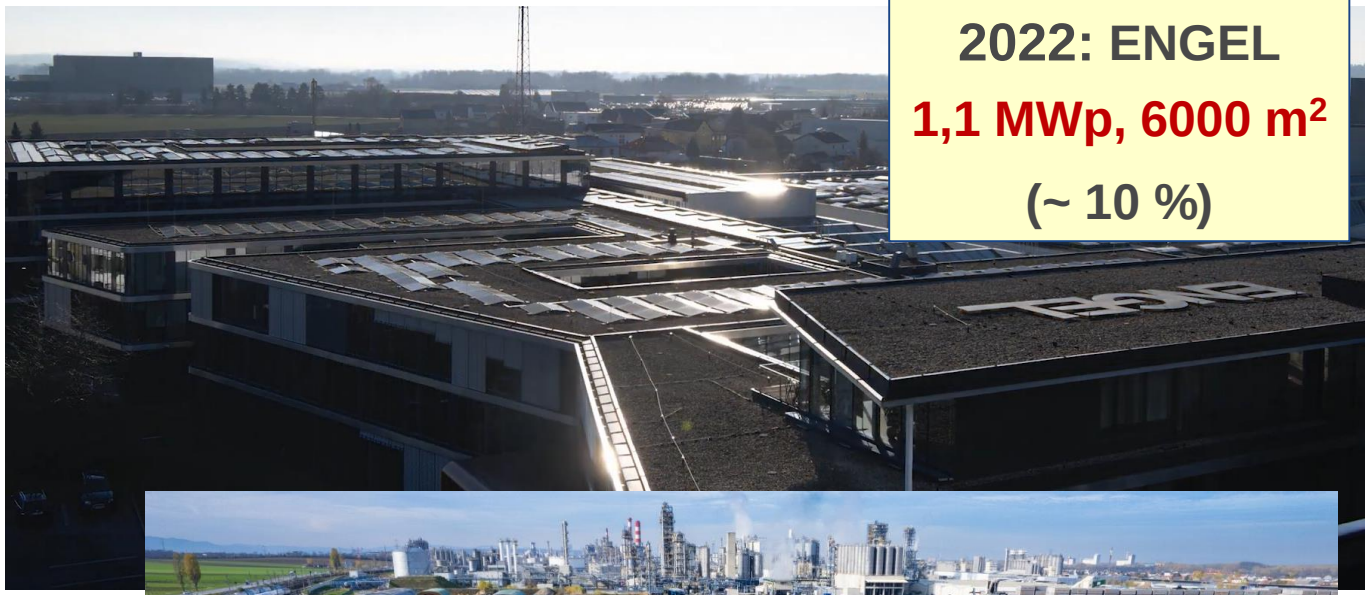
2021: EREMA

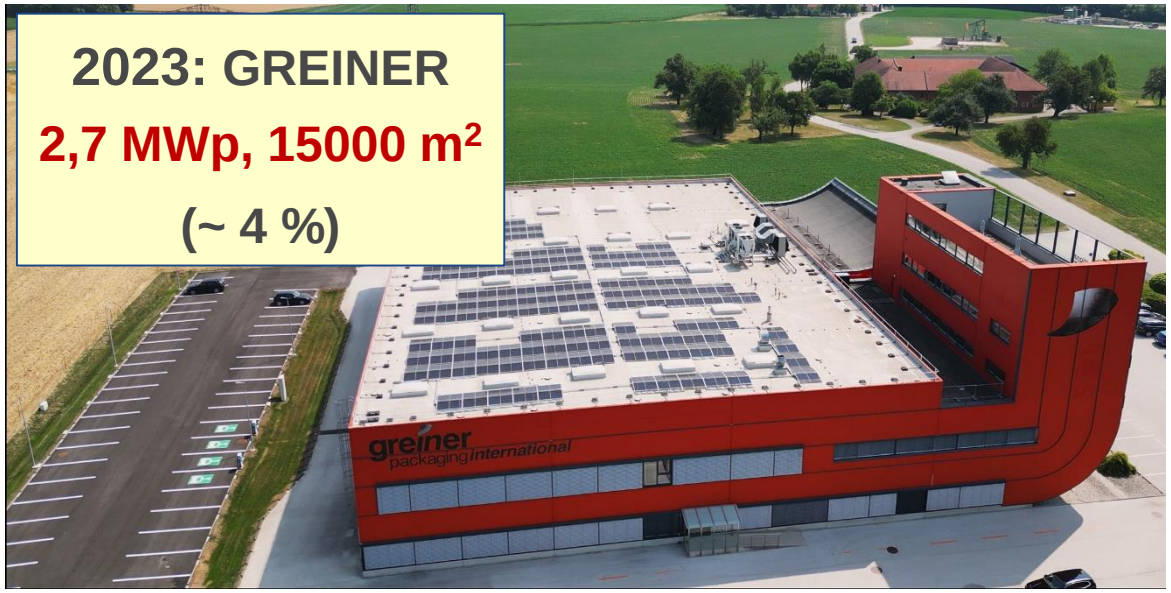
0,12 MWp, 600 m²



2022: ENGEL

1,1 MWp, 6000 m²

(~ 10 %)



2023: GREINER

2,7 MWp, 15000 m²

(~ 4 %)

2022: BOREALIS

4,7 MWp, 75000 m²

PLASTICS INDUSTRY & PHOTOVOLTAICS

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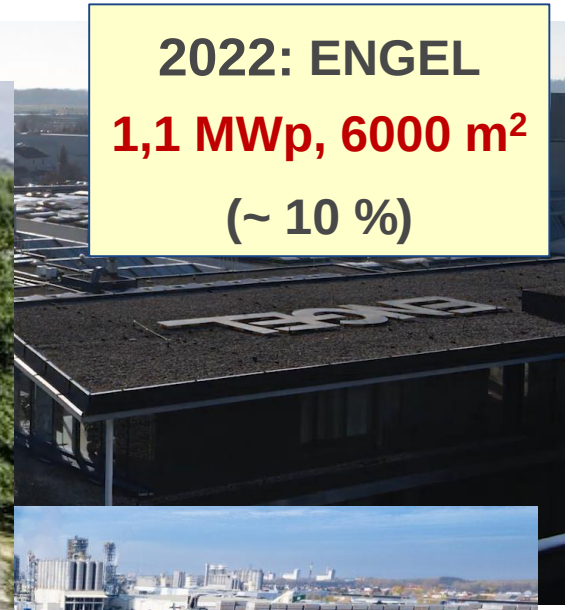
2021: EREMA

0,12 MWp, 600 m²

2019: LIT-OIC

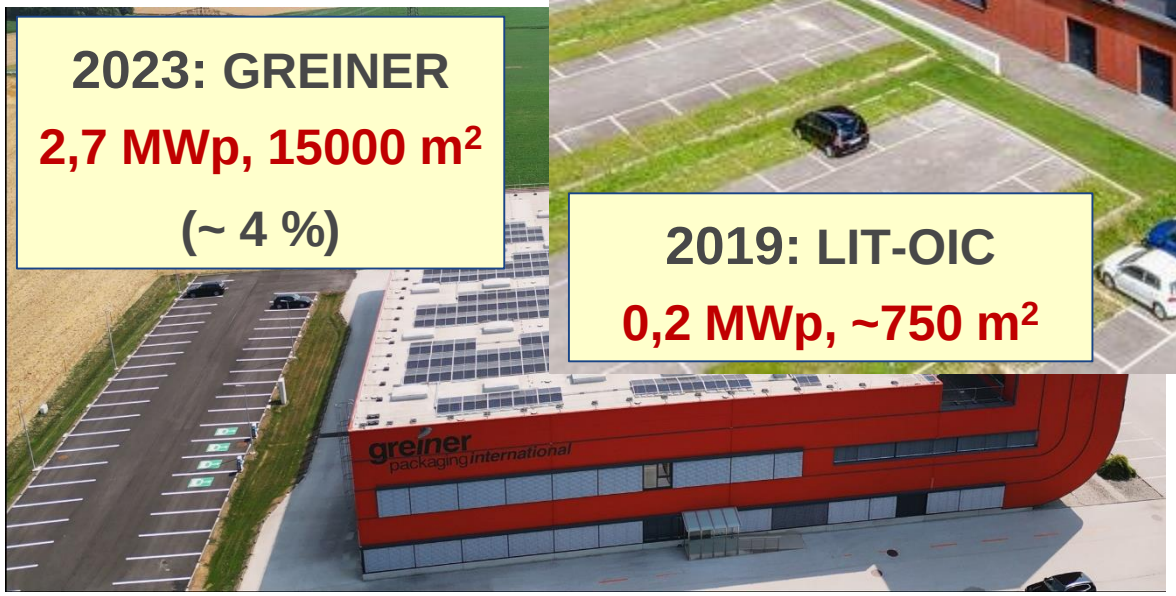
0,2 MWp, ~750 m²



2022: ENGEL

1,1 MWp, 6000 m²

(~ 10 %)



2023: GREINER

2,7 MWp, 15000 m²

(~ 4 %)

2022: BOREALIS

4,7 MWp, 75000 m²

CHRISTIAN DOPPLER LAB AGEPOL

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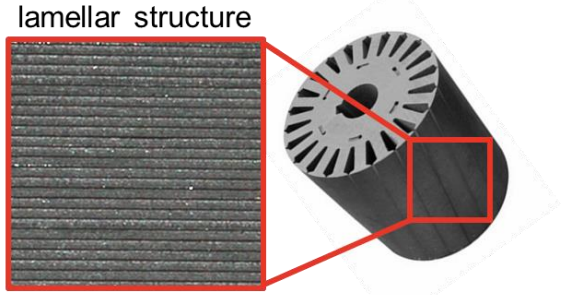
agepol

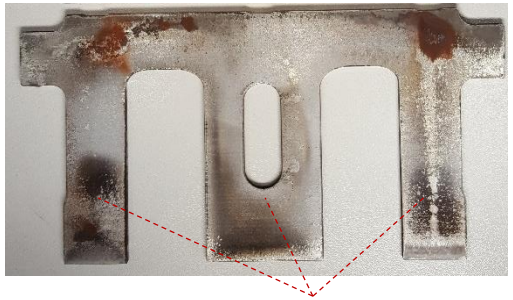
DELAMINATION DRIVEN BY SUPERIMPOSED STRESSES & LOCAL AGEING

voestalpine

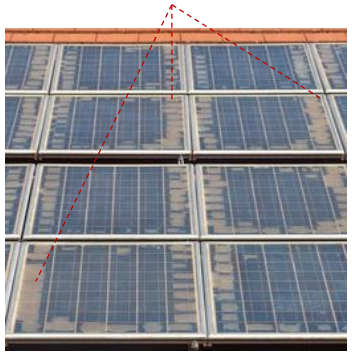
BOREALIS

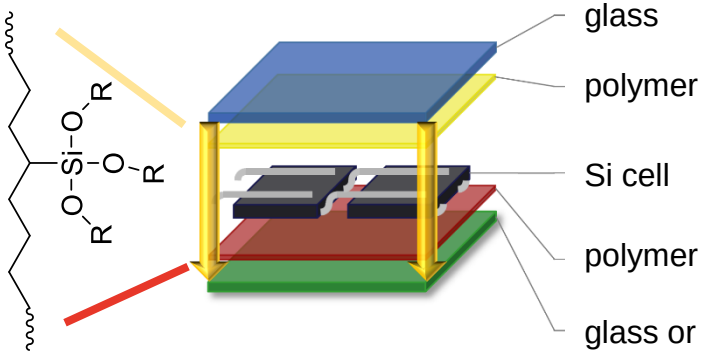


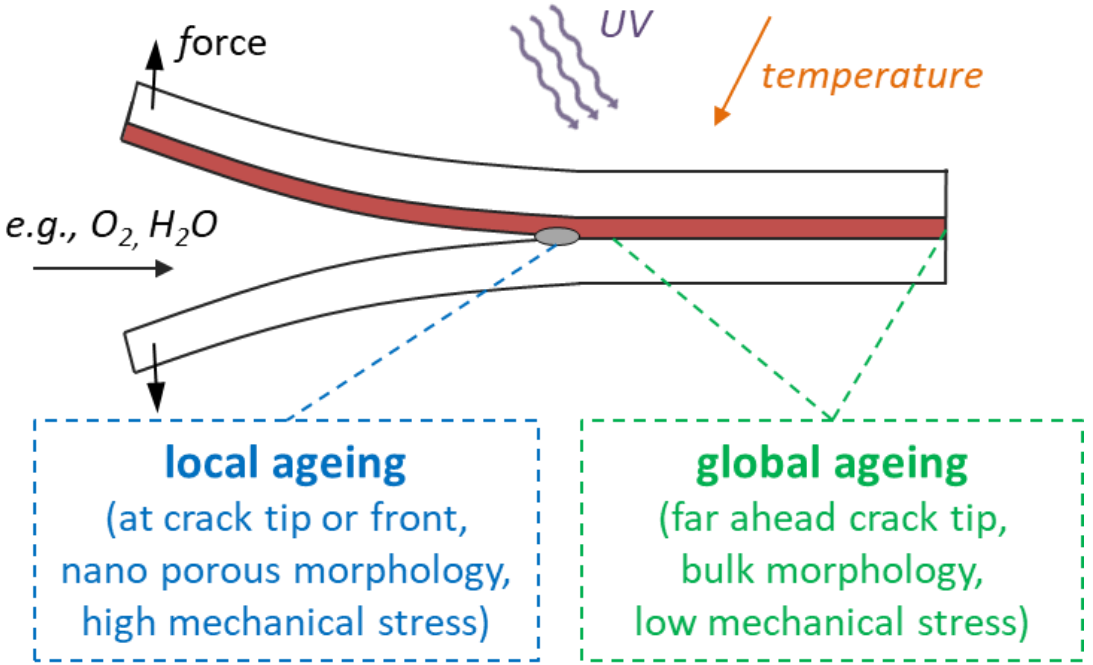
- non-oriented FeSiAl sheet (0.3-1.0 mm)
- thermoset varnish (1-10 µm)



fatigue delamination
(cyclic intermittent)







FACTS & FIGURES:

Budget: 3.5 mio. EURO

Duration: 7 years

Encapsulant Delamination Testing

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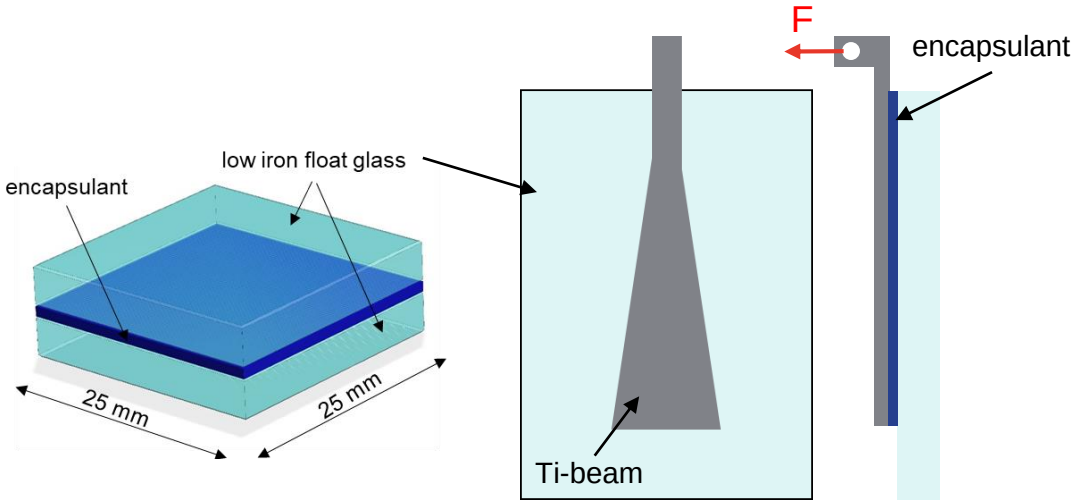
Global Ageing

specimens exposed under harsh environmental conditions & subsequent mechanical testing



compressive shear test

(Tiefenthaler, 2022)

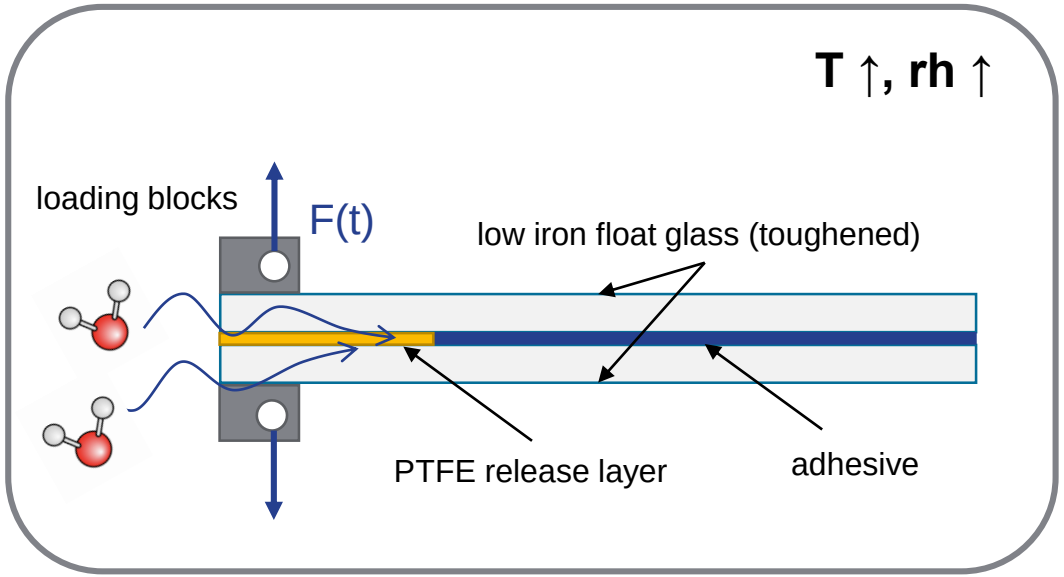
width tapered cantilever beam test

(Dauskardt, 2016)

long exposure times → months to years

Local Ageing

superposition of environmental and service relevant cyclic mechanical loadings



double cantilever beam test

(Riedl, 2022)

potential for highly accelerated lab testing → few days

ETHYLENE COPOLYMERS FOR PV

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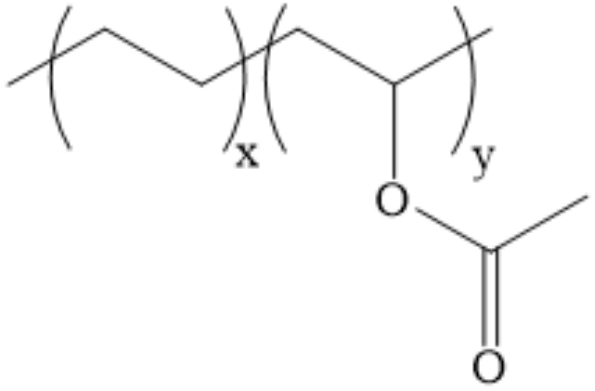
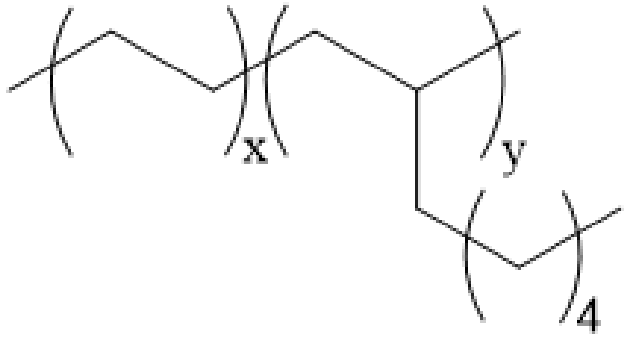
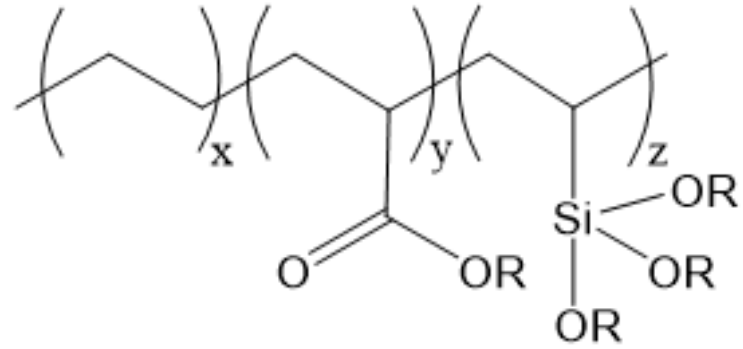
Ethylene Vinylacetate CoPo (EVA)	Polyolefin Elastomer (POE)	Ethylene Acrylate Vinylsilane Terpolymer (BPO)
		
polar → acetic acid	weakly polar (acrylate comonomer)	less polar
cross linker: peroxide + coactivators (Type I or II; e.g., cyanurates or acrylates)		thermoplastic
adhesion promoter: vinylsilane		silane in polymer backbone
stabilization: phosphite, HALS, (phenolic AOs), (UV-absorbers)		stabilization: undisclosed

Evaluaion of UV-transparent EVA vs. POE

LOCAL AGEING – ENVIRONMENTAL FATIGUE

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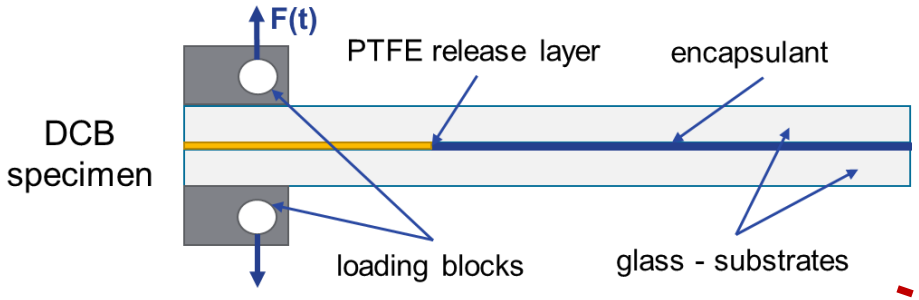
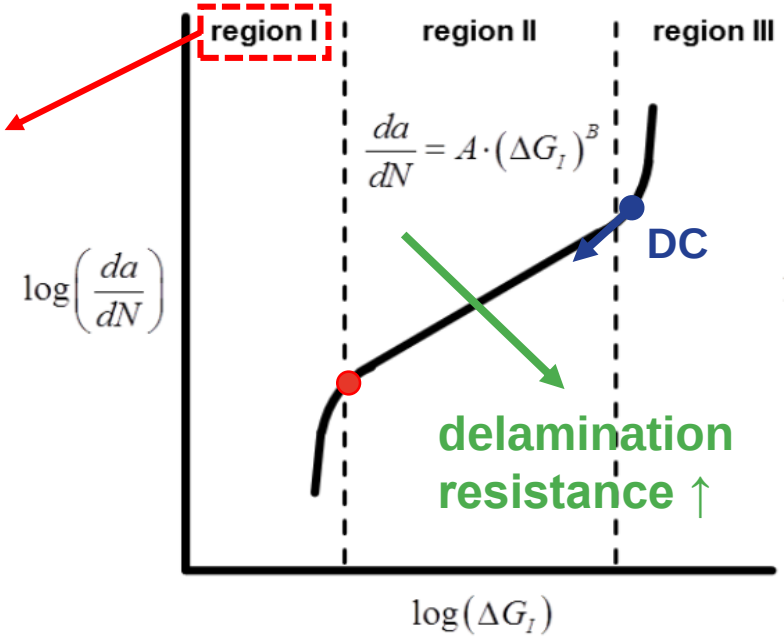
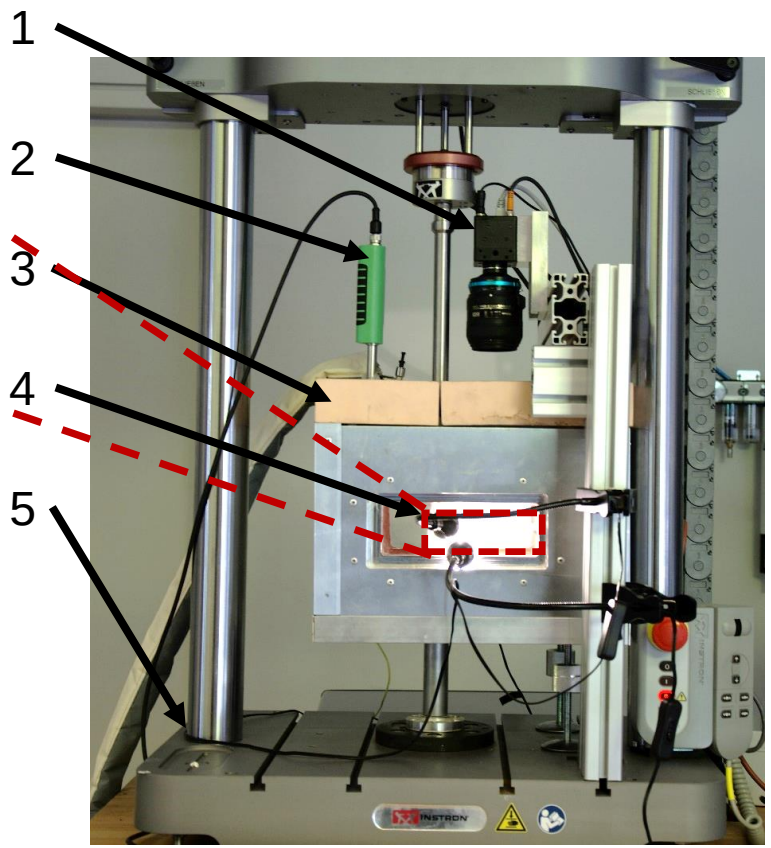


- displacement controlled (DC)
- T = 80°C
- rh = 5% or 70%

threshold region (G_{th})
$da/dN < 10^{-7}$ mm/cycle
very slow crack growth
→ service relevant





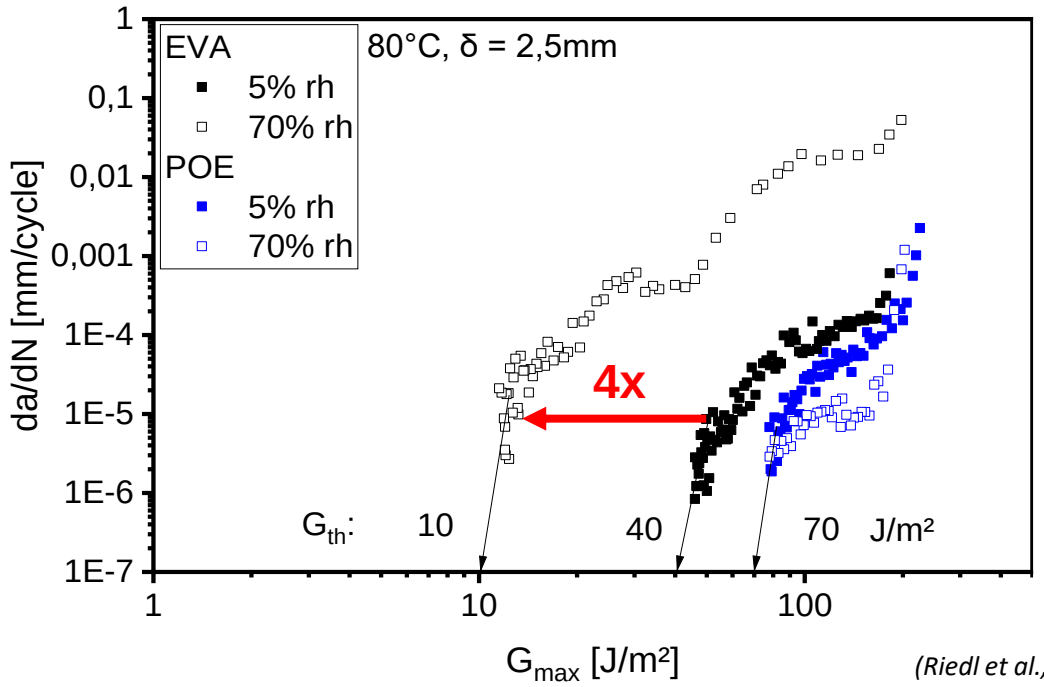
test setup for cyclic delamination tests
1 - Camera system
2 - Thermo-hygrometer
3 - Test chamber
4 - Specimen illumination
5 - Electrodynamical test machine

FCG IN CROSSLINKING ENCAPSULANTS

EFFECT OF HUMIDITY ON FATIGUE CRACK GROWTH

cohesive/interfacial voiding ↑

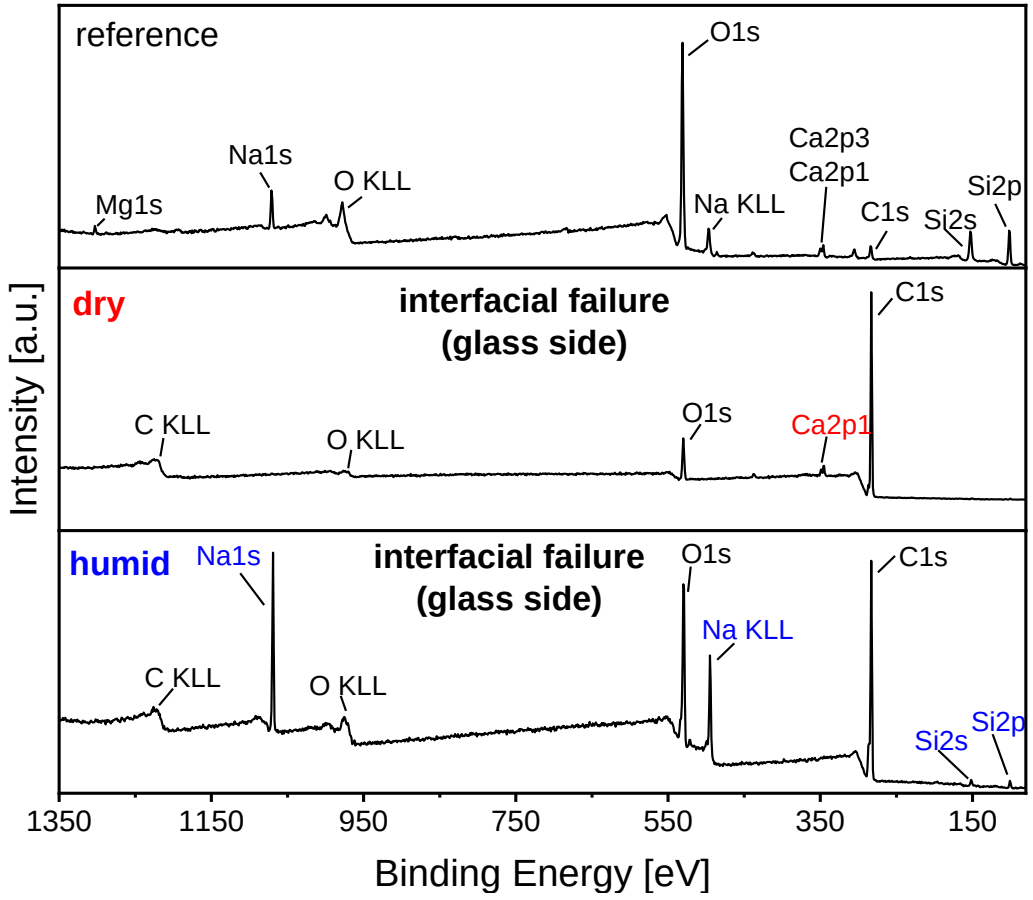
cohesive voiding ↑

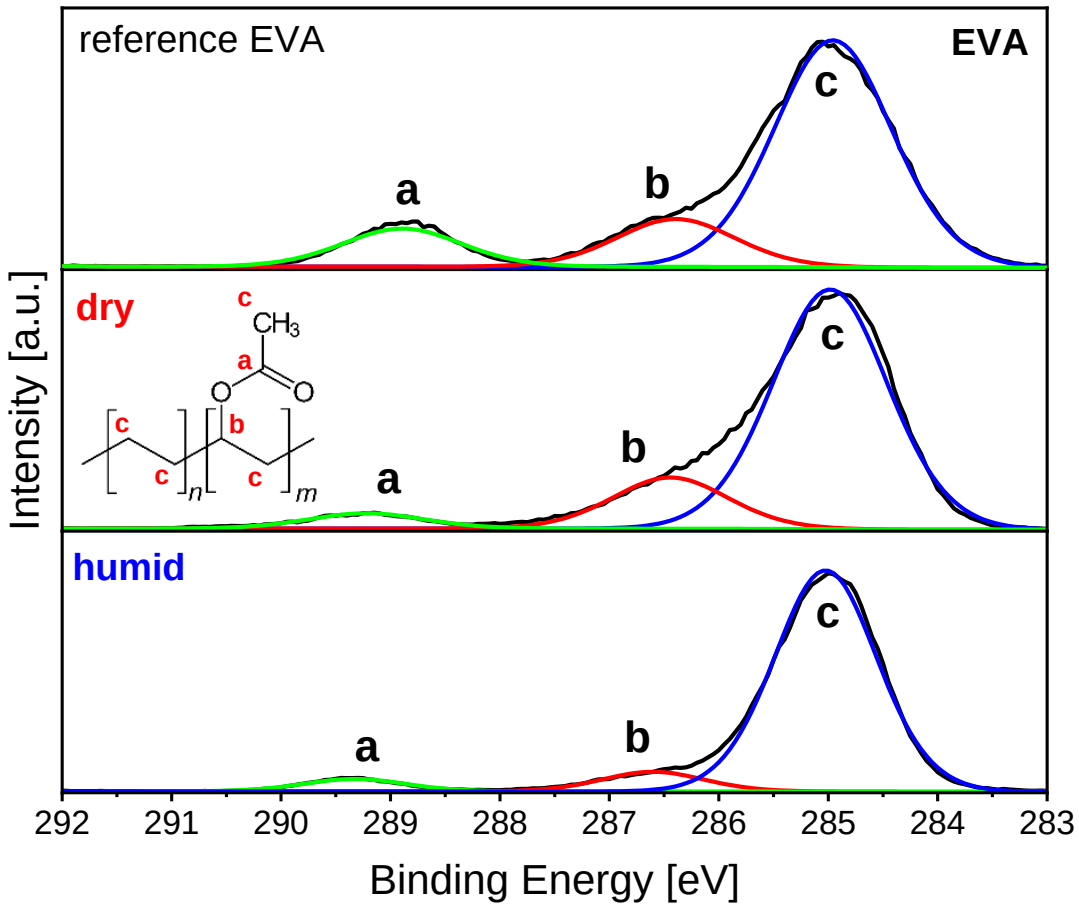


(Riedl et al., 2022)

- void formation and subsequent delamination for both materials
- **superior delamination resistance of glass POE** laminates in hot-dry & hot-humid environment
- **significant reduction** in fatigue threshold of **glass EVA** laminates in **hot-humid** environment

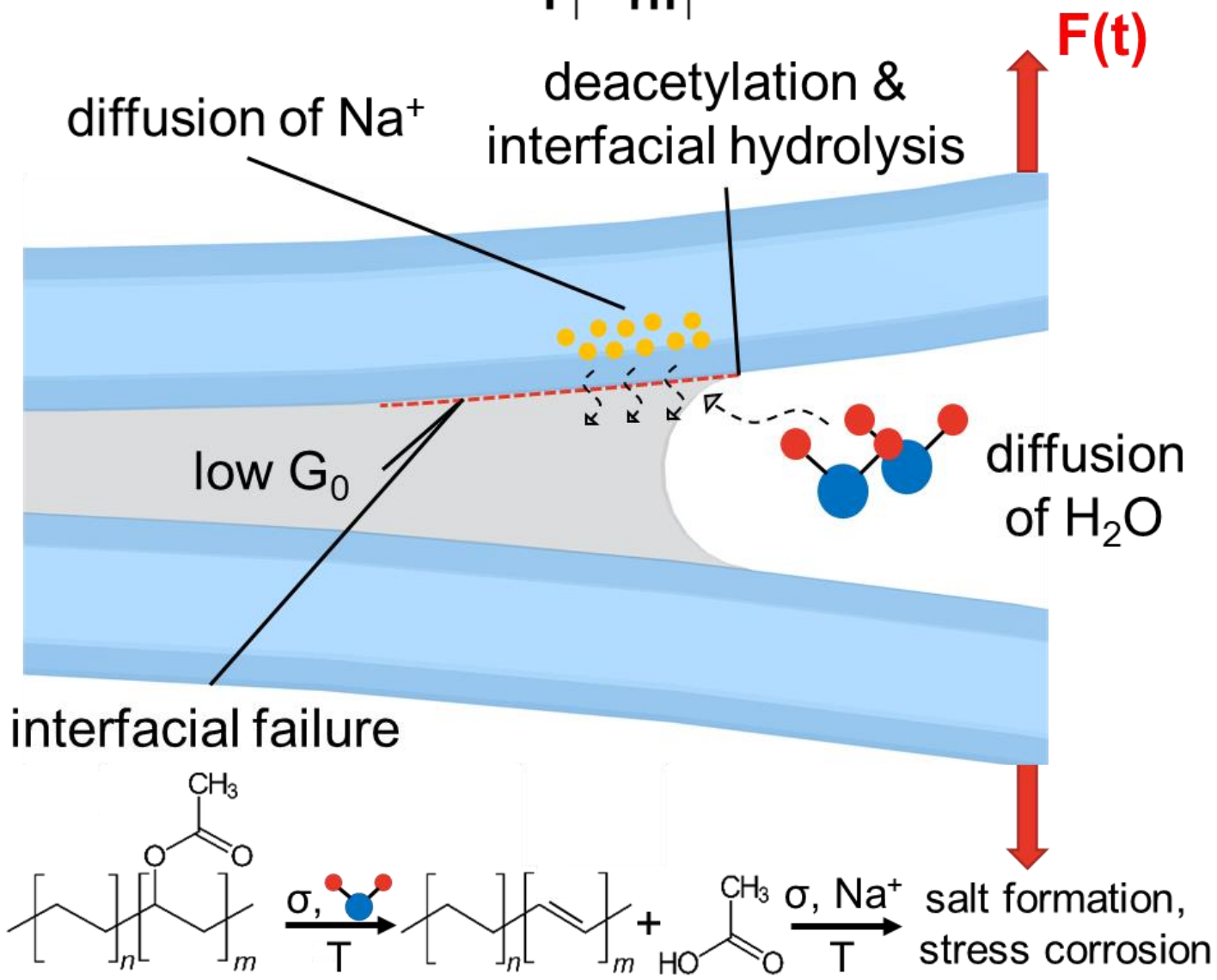
GLASS/EVA FRACTURED SURFACE





Similar results reported by *Thornton et al., 2022* after 10,000 hours of global damp heat aging and subsequent monotonic testing (Na ↑, O1s ↓)

Local ageing corroborated at glass/EVA interface



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local crack tip ageing effects of EVA corroborated within 3 days of testing

→ fast screening of novel material combinations

ELSEVIER

Solar Energy Materials and Solar Cells

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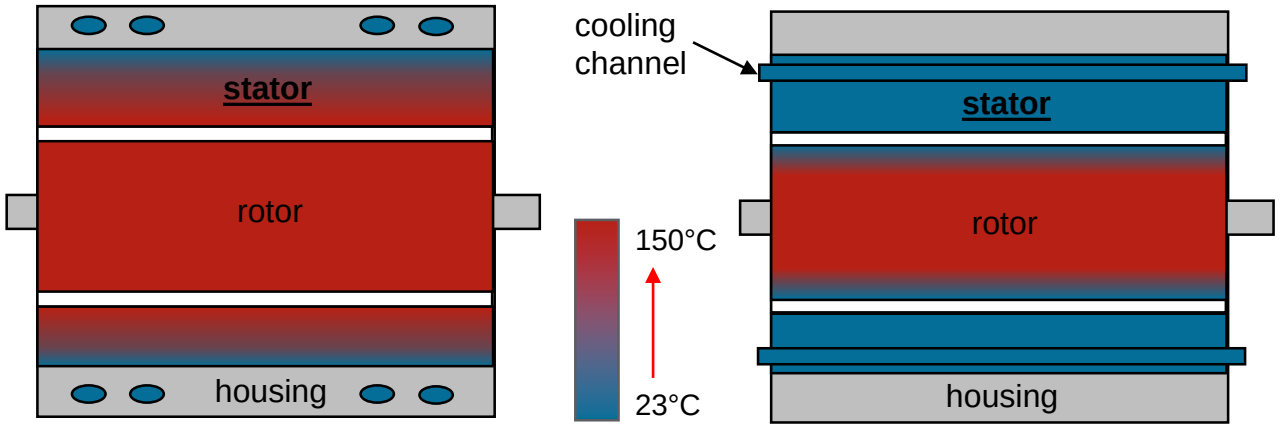
Methodology for local ageing and damage development characterization of solar glass/encapsulant interfaces under superimposed fatigue stresses and environmental influences

Gabriel Riedl [a, b], Gernot M. Wallner [a, b], Robert Pugstaller [a, b], Gary Säckl [a, c], Reinhold H. Dauskardt [d]

ELECTRICAL ENGINES – STEEL/EPOXY

Cooling concepts for steel/epoxy stators



Case 1
Mercedes Benz EQS

- cooling jacket over stator (poor contact)
- delamination: high temperature

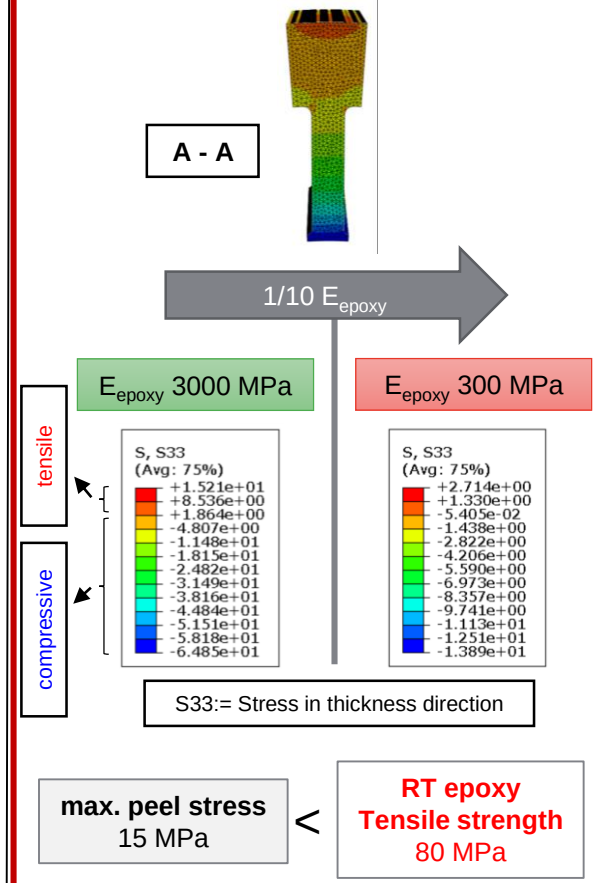
Case 3
Tesla Model S & Y

- cooling channels across stacked stator
- delamination: water/oil based HCF in close contact with laminates

Critical stresses in steel/epoxy laminates

Case 1: T-induced

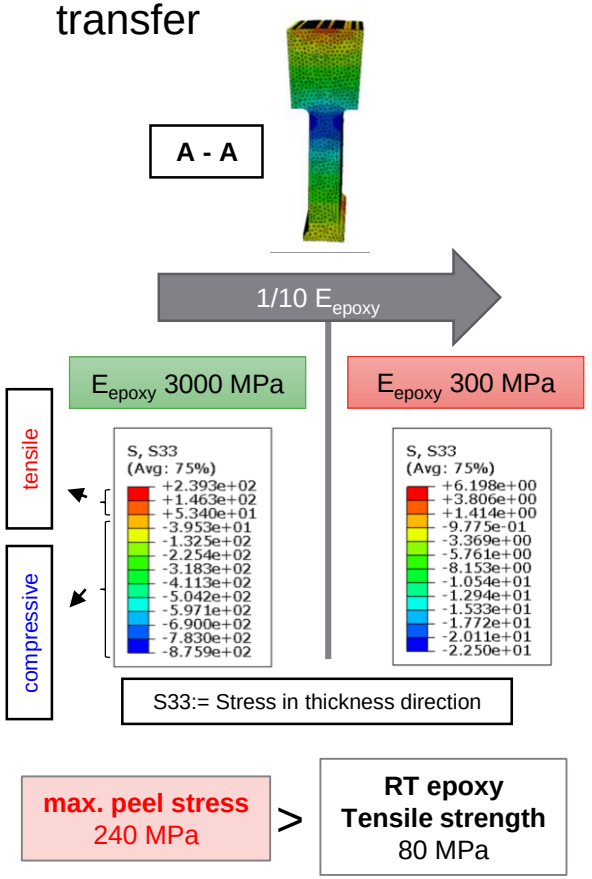
- inside-outside



max. peel stress 15 MPa < **RT epoxy Tensile strength** 80 MPa

Case 2: T & α mismatch

- copper coil induced heat transfer



max. peel stress 240 MPa > **RT epoxy Tensile strength** 80 MPa

ELECTRICAL STEEL/EPOXY

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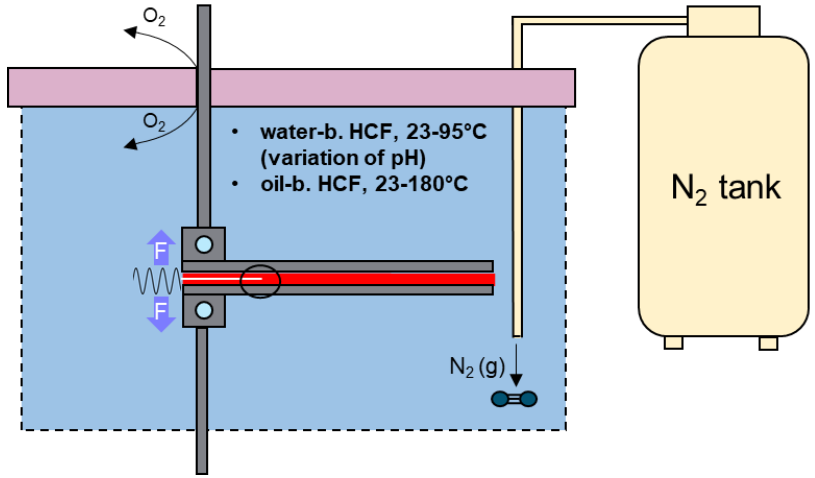
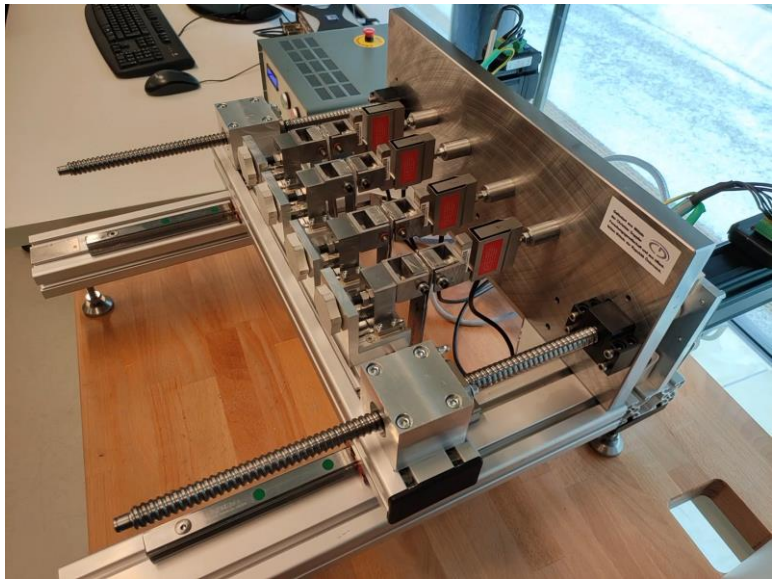
Fatigue test facilities for (heat carrier) fluids

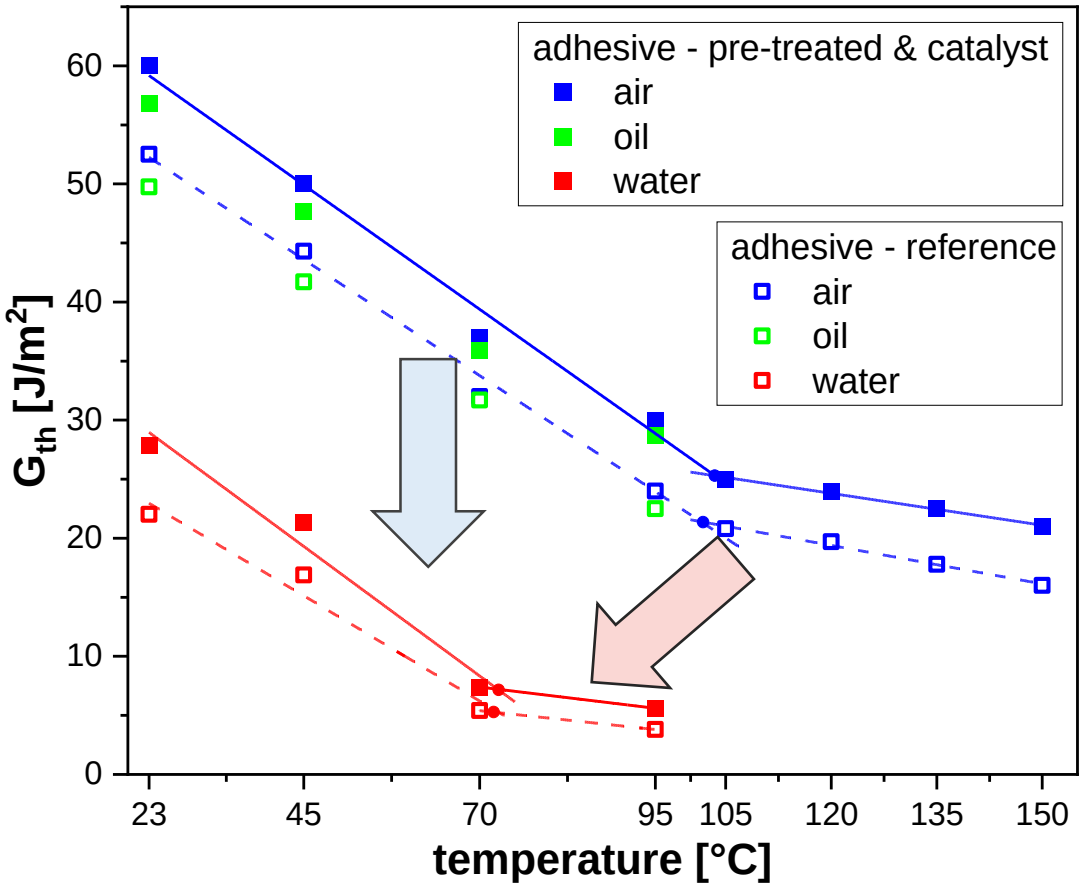


Simultanous multi-specimen testing & vertical positioning



Riedl et al., Eng Fract Mech, 2022

Effect of heat carrier fluid and steel pre-treatment on threshold



- significant reduction of G_{th} in water-HCF
- positive effect of pre-treatment

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Renewable Energy & Polymer Technologies

Generation

Transformation & transportation

Storage & energization

- **Design, manufacturing and performance assessment of durable hybrid components**
- **Debonding & recycling processes for multi-material hybrids**