ANNEX I

Flexible Barrier Materials for the Encapsulation of Electronics

Fundamentals, Barrier Concepts, Measurements and Recent Results

Fraunhofer Institut for Process
Engineering and Packaging, Freising

Flexible Barrier Materials for Vacuum Insulation Panels and Electronic Applications

Fundamentals, Barrier Concepts, Measurements and Recent Results

Fraunhofer Institut for Process Engineering and Packaging, Freising

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Fraunhofer IVV

Joseph von Fraunhofer (1787 – 1826)

© Deutsches Museum

Researcher

→ discovery of the “Fraunhofer lines” in the solar spectrum

Inventor

→ new methods for processing lenses

Entrepreneur

→ director and partner in a glassworks

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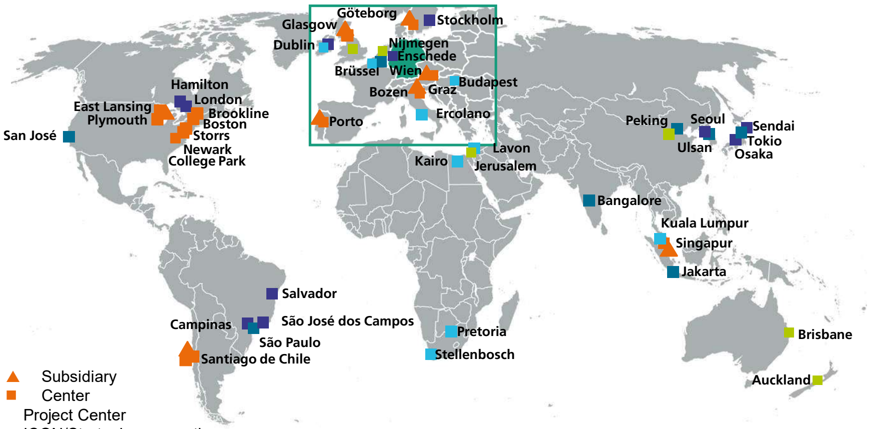
Fraunhofer-Gesellschaft Worldwide



- Subsidiary
- Center
- Project Center
- ICON/Strategic cooperation
- Representative/Marketing Office
- Senior Advisor

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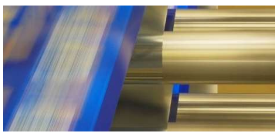
FRAUNHOFER INSTITUTE FOR PROCESS ENGINEERING AND PACKAGING IVV

www.ivv.fraunhofer.de



Fraunhofer IVV – Location Freising – Location Dresden

Institute Head Fraunhofer IVV: Prof. Dr. Andrea Büttner | Prof. Dr.-Ing. Jens-Peter Majschak

Total workforce	269
Scientists and graduates	143
Postgraduate students	36
Total Budget	€ 22,2 million

Total workforce	56
Scientists and graduates	41
Postgraduate students	5
Total Budget	€ 4,7 million

(Status April 2021)

(Stand: 2021)

Possible Forms of Collaboration

Publicly funded projects

- Contributions of the companies to the project usually in the form of services, rarely money
- Pre-competitive research possible
- Project results publicly accessible

Bilateral projects

- Offer drawn up to meet the precise needs of the commissioning party
- Project starts immediately after the research is commissioned
- Project results exclusively for the commissioning party
- Confidentiality assured

Our Business Fields and Core Areas of Expertise

Food
High-quality, healthy and convenient foods and ingredients

Packaging
Safe, customer-friendly and recyclabel packaging materials

Processing Machinery
Optimized production and cleaning processes and digital solutions for Industry 4.0

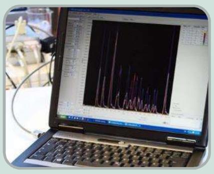
Product Performance
Holistic sensory optimization of raw materials and market-ready products

Recycling and Environment
Innovative recycling technologies, bio-based additives and environmental analysis

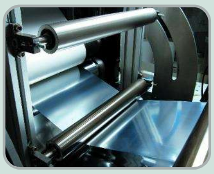
Material Development – who we are

Functional Materials
Development of films with barrier properties specially adapted to your requirements

Biobased Materials
Development of bio- and fiber-based materials and packaging



Shelf-Life Modelling
Predicting the shelf life of products in new packaging and optimizing packaging



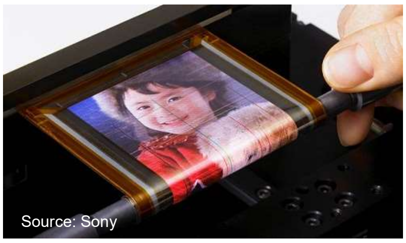
Packaging pilot plant
Product optimization on a pilot scale with low amount of materials/ test processability of new materials and material combinations

Packaging Lab
Evaluation of mechanical and optical parameters as well as permeability as an elementary component of your material development and quality assurance

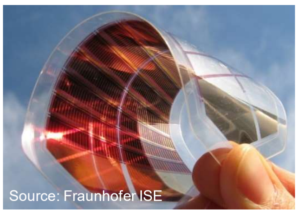
Outline

- Barrier requirements of various products
- Gas permeation through polymers
- High barrier films: Production, permeation mechanisms, challenges
- Barrier performance measurements
- Summary and outlook

Flexible Electronics


Source: Sony

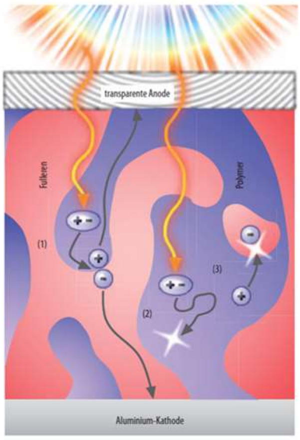

Source: Fraunhofer IAP


Source: Fraunhofer ISE

Source: Belectric OPV


Source: Fraunhofer FEP

Flexible Electronics



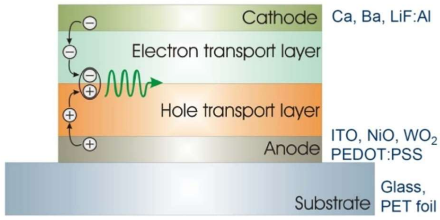
Advantages

- Cost efficient R2R-production
- Adaptable to curved surfaces
- Integration into flexible materials
- Ressource and energy efficient

Disadvantages

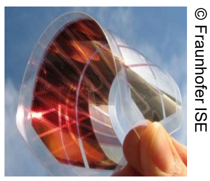
- Degradation by oxygen and water vapor

→Limited lifetime



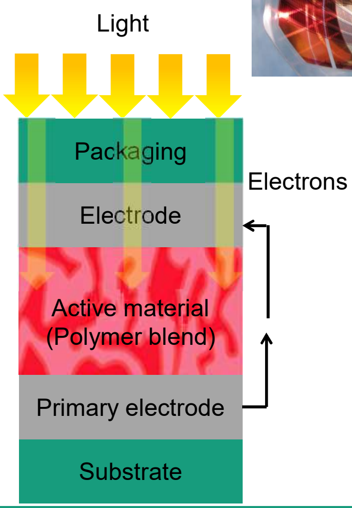
Left: OPVC (Deibel et al., Physik Journal 7 (2008) Nr. 5, 51)
Right: OLED (W. Brütting, Forum Materialien für die Polymerelektronik, Fürth, 6.11.2008)

Flexible Electronics - Organic Photovoltaics

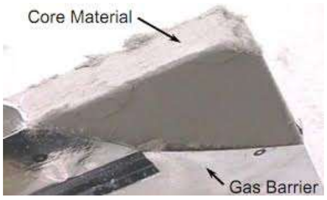


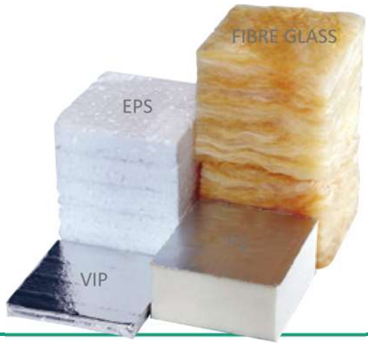
- Flexible devices are light-weight, unbreakable
- Low-cost roll-to-roll production instead of costly batch processes
- Low consumption of material and energy
- High productivity

Organic active layers are sensitive to oxygen and water vapor!



Vacuum Insulation Panels





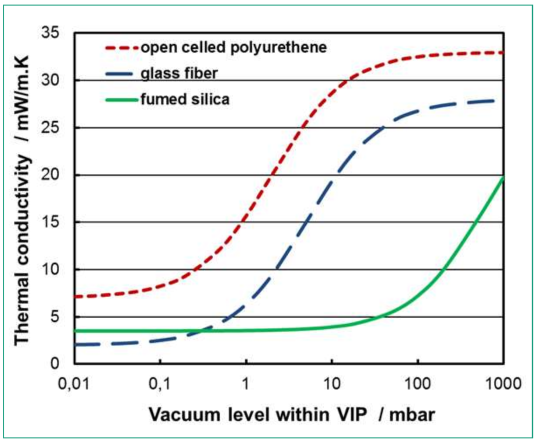
- Open porous core material
- Evacuation ⇒ Low heat conduction

ARCELIK A.S. (Beko Brand)

Source: Annex 39

Upper picture source: Fraunhofer IVV
Bottom picture source: http://anjeystroy.com

Vacuum Insulation Panels

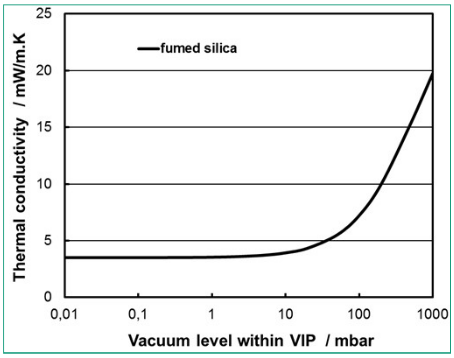


$$\lambda(p) = \lambda_{initial} + \frac{\lambda_{gas}}{\left(1 + \frac{p_{1/2}}{p}\right)}$$

Source picture: http://www.vacuum-panels.co.uk/

Vacuum Insulation Panels

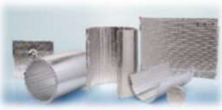
- Evacuation ➔ Low heat conduction
- Air and water vapor permeation ➔ Pressure increase ➔ Loss of thermal insulation

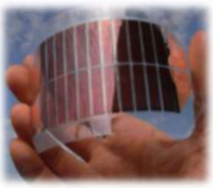


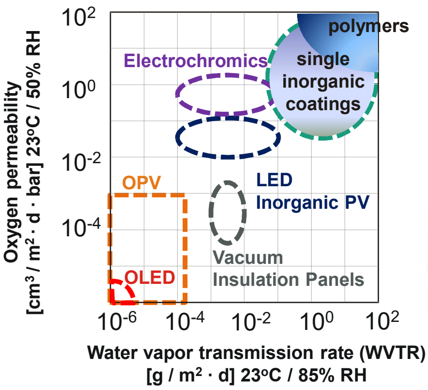
ARCELIK A.S. (Beko Brand)

va-Q-tec AG, Building in Munich, Annex 39

Barrier Requirements of Various Products

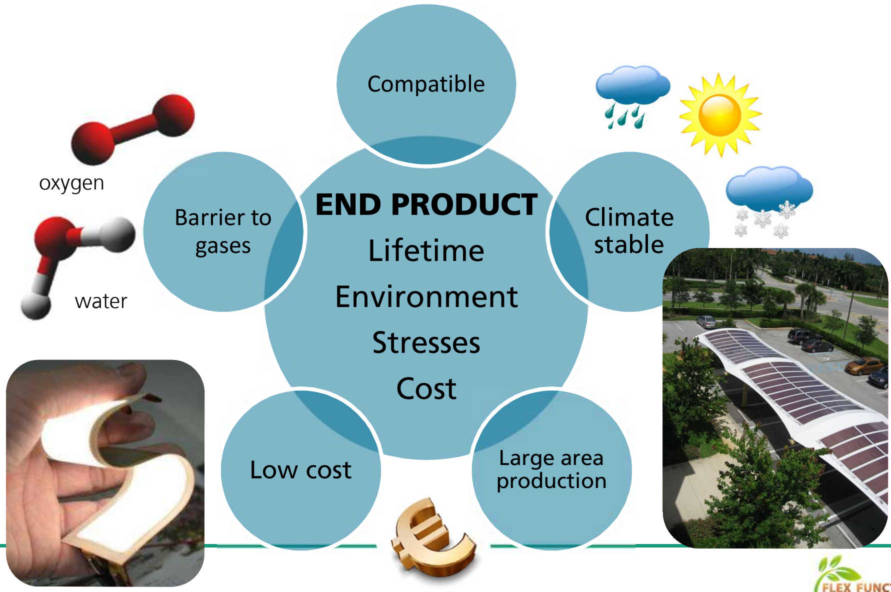






Left: top, bottom: Fraunhofer ISE, Fraunhofer IAP, Right bottom: Prof. Jan Cremers

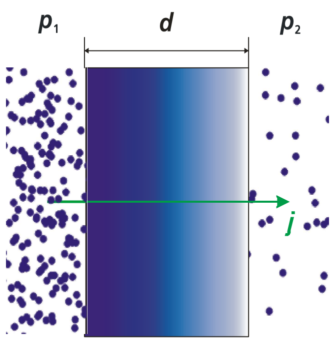
Requirements for Barrier films Depend on Application



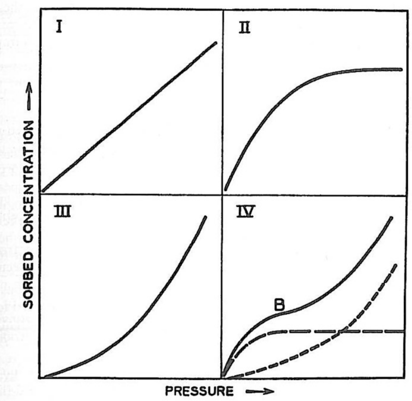
Permeation through Polymers: Solution diffusion model

Steps of permeation process

- Adsorption of permeant's molecules at left polymer surface and dissolution in polymer
- Diffusion through polymer
- Desorption from right polymer surface



Sorption in polymers

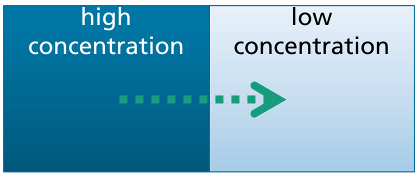


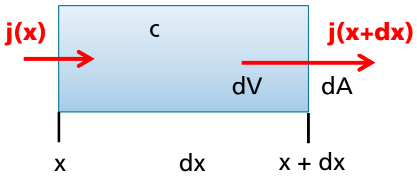
Sorption isotherms (C.E. Rogers, in J. Comyn (Ed.), Polymer Permeability ,1985, 11–73)

Sorption isotherm

- Equilibrium between gas and dissolved phase of permeant
- Simple case: **Henry‘s law** $c = S\,p$
  - *c*: concentration; *p*: partial pressure; *S*: solubility
  - Valid for low concentration or for negligible interaction between permeant and polymer

Diffusion in Polymers





Fick‘s 1st law

- Concentration gradient is driving force of diffusion

$$j = \frac{Q}{At}$$

$$j = -D \operatorname{grad} c = -D \left(\frac{\partial c}{\partial x}, \frac{\partial c}{\partial y}, \frac{\partial c}{\partial z}\right)^{\mathrm{T}}$$

Continuity equation

$$\frac{\partial c}{\partial t} + \operatorname{div} j = \frac{\partial c}{\partial t} + \frac{\partial j_x}{\partial x} + \frac{\partial j_y}{\partial y} + \frac{\partial j_z}{\partial z} = 0$$

- Conservation of material amount

⇒ **Fick‘s 2nd law (Diffusion equation)**

$$\frac{\partial c}{\partial t} = D\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} + \frac{\partial^2 c}{\partial z^2}\right)$$

Permeation through Polymers

Fick's First Law of Diffusion:

$$J = \frac{Q}{At} \qquad J = -D\left(\frac{\partial c}{\partial x}\right)$$

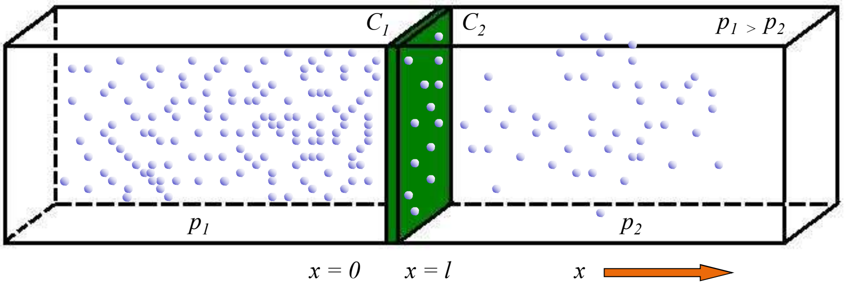
Fick's Second Law of Diffusion:

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2}$$

$$J = -D\frac{dc}{dx} = \frac{D(C_1 - C_2)}{l}$$

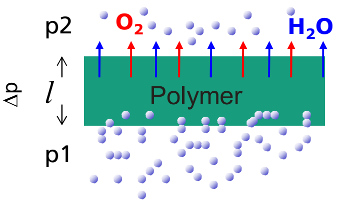
$$c = Sp$$

$$J = DS(p_1 - p_2)/l \qquad P = D \times S$$

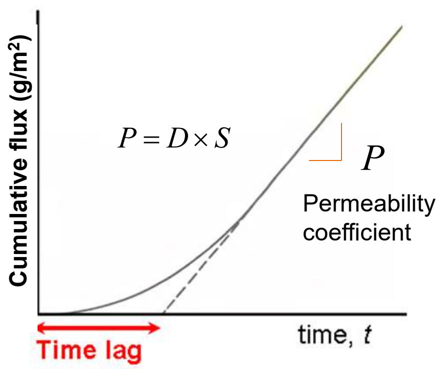


Basic Principles of Permeation

Solution-diffusion model

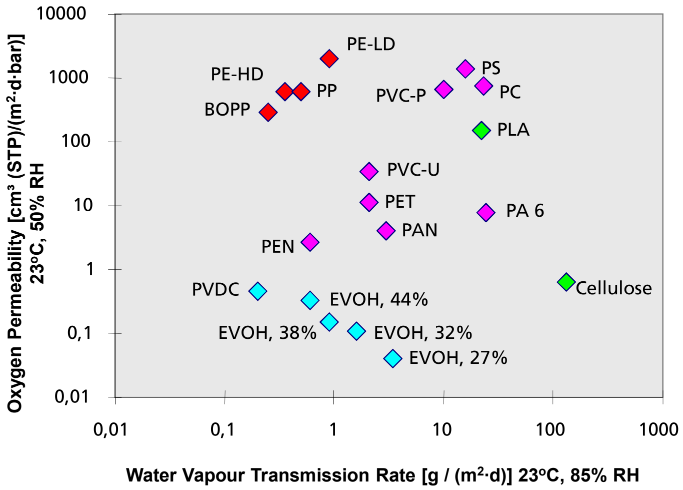


Henry's Law: $c = Sp$



Time lag: $l^2 / 6D$

Barrier Properties of Polymer Films



Polymer layer thickness: 100 µm

Outline

- Barrier requirements of various products
- Gas permeation through polymers
- High barrier films: Production, permeation mechanisms, challenges
- Barrier performance measurements
- Summary and outlook

Single Inorganic Barrier Layers

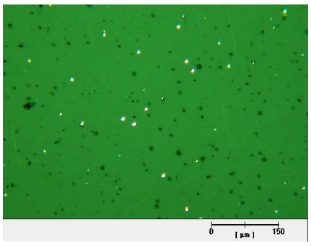
Barrier materials

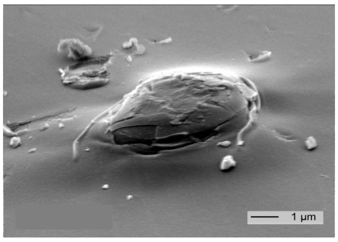
- Metals, e.g. Aluminium
- Transparent oxides and nitrides
  - SiO_2, Al_2O_3, Zn_2SnO_4, Si_3N_4,…
- Graphene, …

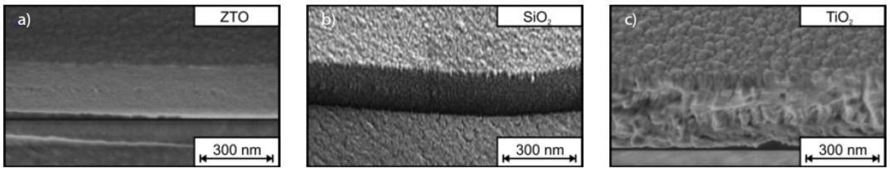
Deposition methods

- Physical vapor deposition (PVD)
  - Thermal or electron beam evaporation
  - Sputtering
- Plasma enhanced chemical vapor deposition (PECVD)
- Atomic layer deposition (ALD)

Permeation Through Inorganic Barrier Layers







Top: Defects in Al and SiOx (Fraunhofer IVV)
Bottom: Sputterered layer morphologies (Fahlteich et al., Vakuum in Forschung und Praxis 23 (2011) 4, 29–37)

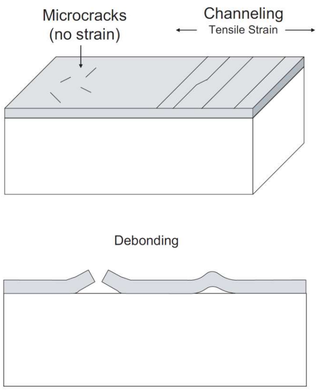
Permeation Through Inorganic Barrier Layers

Mechanical stress in inorganic layers

- Intrinsic stress arising during film growth
- Subsequent roll-to-roll processes
- Application in flexible electronic devices

Consequences of mechanical stress

- Formation of cracks within inorganic layers
- Delamination of layers from substrate
- ⇒ Loss of barrier performance



Primary failure modes for brittle films on polymer substrates, Materials Today 9 (2006) 4, 38-45

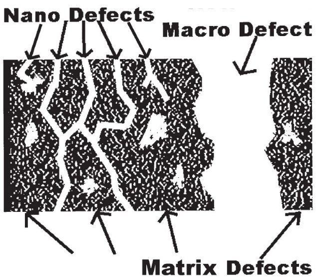
Permeation Through Inorganic Barrier Layers

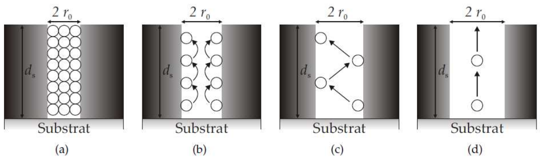
Macrodefects

- Size: Nanometer up to micrometer; Localized positions
- Unhindered transport: Free diffusion (d), Knudsen diffusion, molecular flow (c)

Microdefects (Nanodefects)

- Size: Sub-nanometer up to nanometer; Quasi-homogeneously distributed
- Hindered transport: Surface diffusion (b), capillary condensation (a)





Left: Affinito, Hilliard, A New Class of Ultra-Barrier Materials, 47th Annual Technical Conference Proceedings SVC, 2004, 563-593
Right: J. Fahlteich et al., Transparente Hochbarriereschichten auf flexiblen Substraten, Dissertation, Chemnitz, 2010

Modelling of Permeation Through Barrier Films

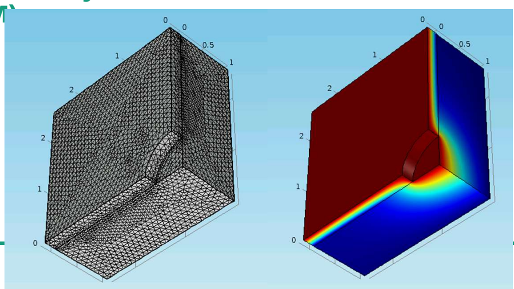
Polymeric materials

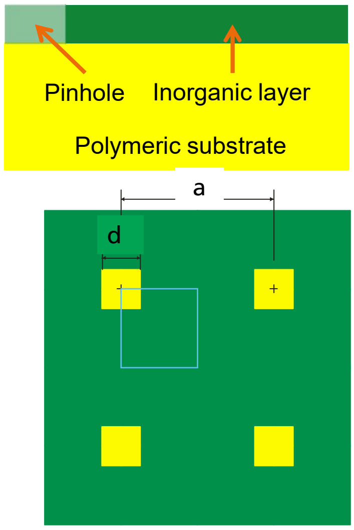
- Diffusion equation

Inorganic layer

- Permeation of oxygen only through pinholes ⇒ boundary condition
- Permeation of water vapor also through inorganic matrix (i.e. microdefects)

⇒ **Numerical solution of diffusion equation by finite element method (FEM)**

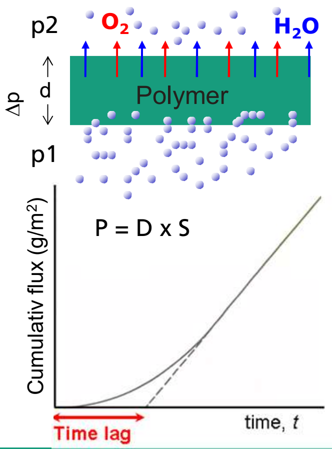




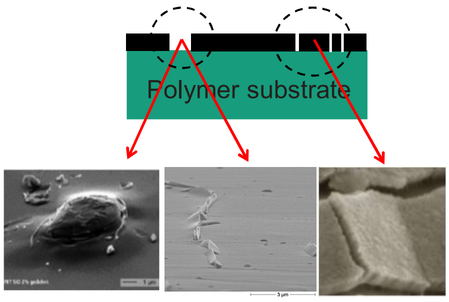
Source:
Oliver Miesbauer

Permeation through Single Inorganic Barrier Layers

Solution-diffusion model



„Defect-dominated“ permeation mechanisms



SEM picture: Defects due to anti-blocking particles

SEM picture: Defects resulting due to thermal stress

SEM picture: Porosity and surface roughness

Inorganic layer coatings: Al, AlO_x, SiO_x

High Barrier Films

- Permeation through thin films:
  Permeation is caused by defects.
- Defects caused by: particles, scratches, non perfect film formation, stress in grown films….
- Approach for the reduction of number and size of defects leading to decreasing permeation

Single inorganic layers

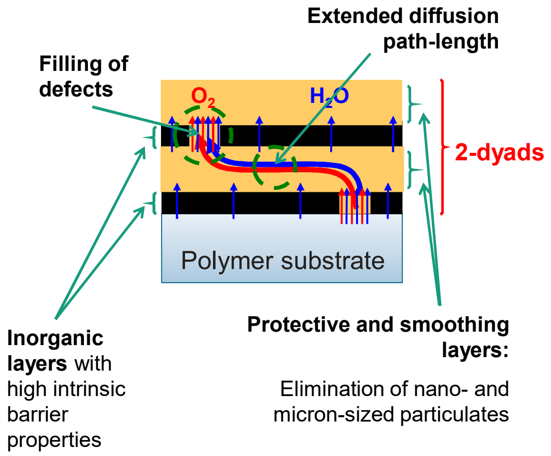
- Large influence of substrate
- Layers are sensitive to mechanical stress
- Defect free deposition needed - ALD

Multi layers

- Combination of barrier layers and smoothening layers, e.g. thin polymer films
- Wet chemical processes for the deposition of the interlayers

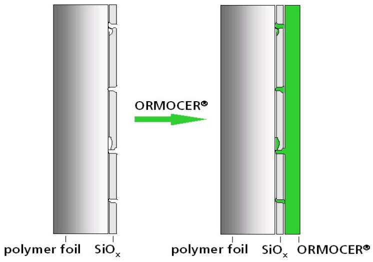
Multilayer High Barrier Films

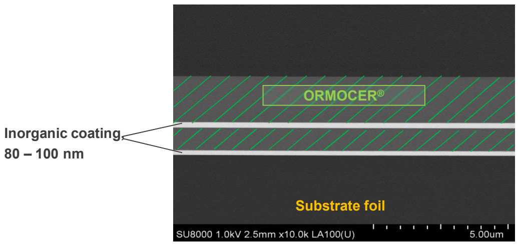
Ultrabarrier Stack: Alternating inorganic/organic layers



High Barrier Films for Device Encapsulation

Barrier Lacquer ORMOCER®





Fraunhofer ISC

http://www.polo.fraunhofer.de/
Fraunhofer Polymer Surfaces Alliance POLO®

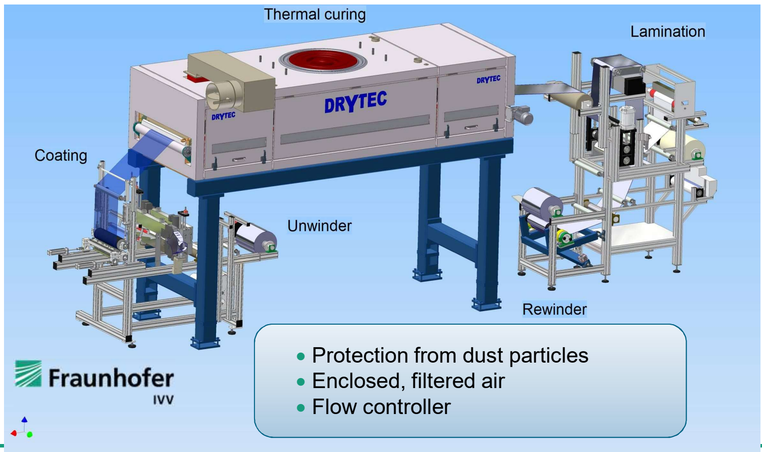
Fraunhofer POLO

FLEX FUNCTION 2 SUSTAIN

Multilayer High Barrier Film Production

Coating Technologies: Roll-to-Roll Processes

Lamination / Lacquering under Clean-Room Environment



FLEX FUNCTION 2 SUSTAIN

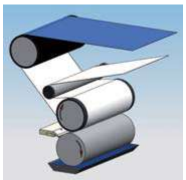
Multilayer High Barrier Film Production

Coating Technologies: Roll-to-Roll Processes

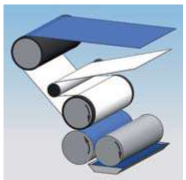
Lamination / Lacquering under Clean-Room Environment

Wet chemical coating process

- Choice of coating and curing process and parameters depends on:
  - Substrate, e.g. surface morphology, surface tension, dimensional stability
  - Properties of the coating material, e.g. rheology, viscosity



Coating with gravure rollers

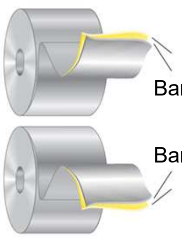


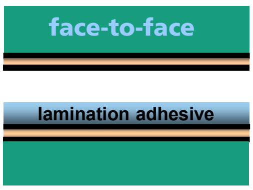
Coating with smooth rollers

Source: A. Glawe, KROENERT

Multilayer High Barrier Film Production: Low-cost

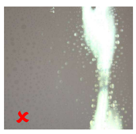
Laminated Multilayered Structures





✓ Higher mechanical stability
× Thicker structures

Challenge: Proper adhesive selection
Thermal stability problem: 85°C/85%RH



High Barrier Films for Device Encapsulation

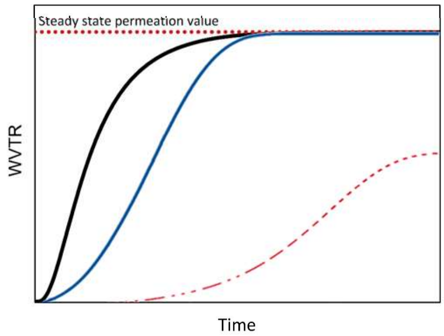
Ultrabarrier Stack: Alternating inorganic/organic layers

Alternating inorganic barrier and organic intermediate layers

- Reduction in WVTR
- Elongation of time-lag

Parameters effecting barrier performance

- Diffusion, Solubility, Permeability Coefficient of each single layer
- Layer sequence and thickness



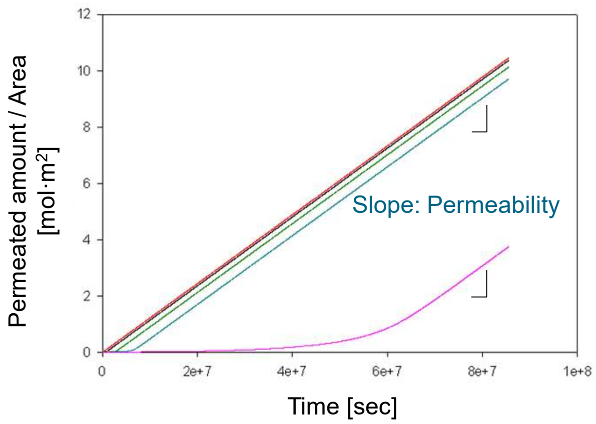
Experimental and Theoretical Studies on the Time-Dependent Permeation Through Multilayered Encapsulation Films for Flexible Organic Electronics, Oliver Miesbauer, June 5 (15:00), Web Coating and Handling

High Barrier Films for Device Encapsulation

Ultrabarrier Stack: Alternating inorganic/organic layers

Optimisation of multilayer films for low permeability and long time lag

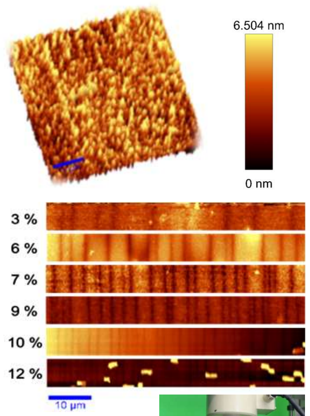
- Increase of number of dyads
- Integration of active absorbers into multilayers



High Barrier Film Production

Biggest Challenges

- **Substrate quality:**
  - Cleanliness, surface roughness
- **Thermal and mechanical stability:**
  - Substrate and barrier layers
- **Process conditions:**
  - Temperature, Pressure (lamination)
  - Web-speed, web tension
  - Dust-free coating, no contact on coated side
- **Quality Control:**
  - Inline (layer thickness, crosslinking degree)
  - Off-line (permeation, adhesion, bending stability)



Any Questions?

Outline

Barrier requirements of various products

Gas permeation through polymers

High barrier films: Production, permeation

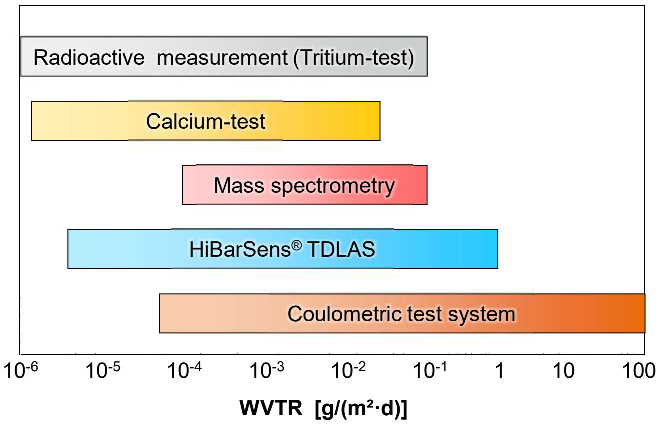
mechanisms, challenges

Barrier performance measurements

Summary and outlook

High Barrier Performance Measurements for Electronics

Water Vapor Transmission Rate (WVTR) Measurement Tools



None of the methods simulate a real device test!

Test conditions

- 23°C / 85% RH: ambient
- 38°C / 90% RH: tropical
- 60°C / 90% RH: accelerated aging
- 85°C / 85% RH: damp-heat-test

Graph modified from C. Boeffel et al. "Ultra-high barrier substrates and ALD layers for the encapsulation of organic electronic devices" ISFOE14

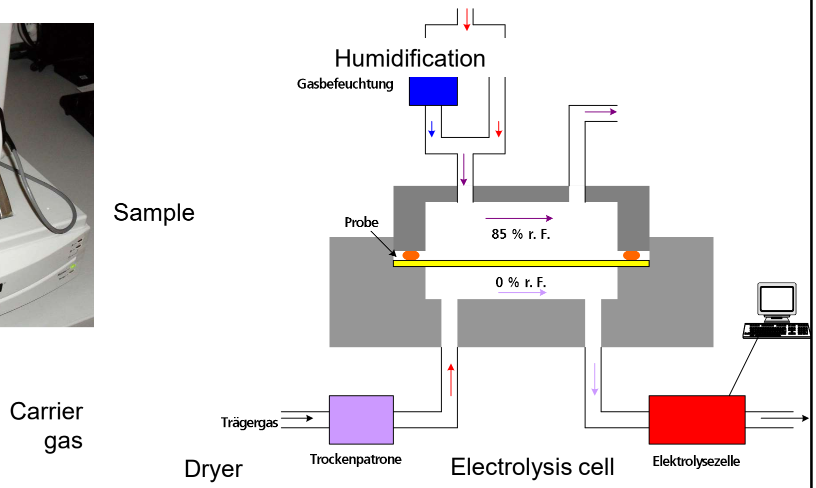
High Barrier Performance Measurements for Electronics

Water Vapor Transmission Rate (WVTR): Coulometric Test

Mocon® Aquatran® Model 2

Detection limit:

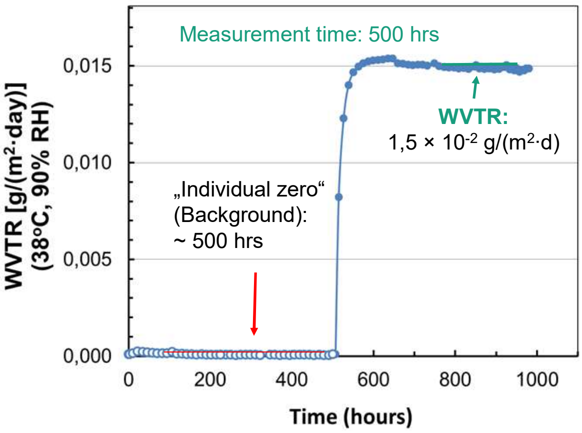
5 x 10^{-5} g/(m^2·d)



High Barrier Performance Measurements for Electronics

Important Factors

- High WVTRs with short time lags ➔ not critical!

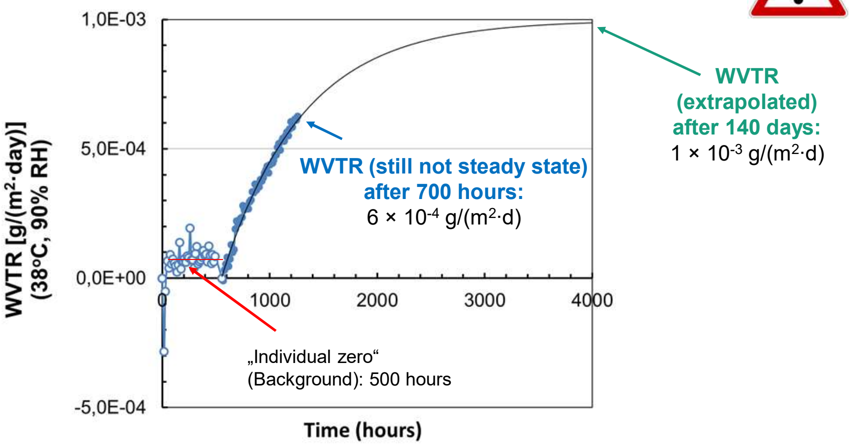


Mocon® AQUATRAN® Model 2

High Barrier Performance Measurements for Electronics

Important Factors

- Low WVTRs (< 5 × 10^{-3} g/(m^2·d)) with long time lags ➔ Pay attention



Mocon® AQUATRAN® Model 2

High Barrier Performance Measurements for Electronics

Important Factors

- Evaluation of measurement curves can be difficult due to the complicated water vapor permeation mechanisms in multilayered structures

- Keep in mind:
  - Pre-conditioning of samples before testing
  - Sufficient measurement duration to ensure the steady state

High Barrier Performance Measurements for VIPs

Important Factors and Limitations

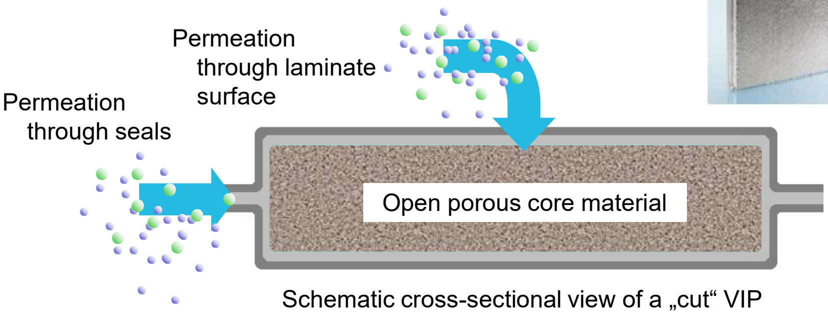
- Barrier performance of VIP envelope before and after VIP production, not comparable
- Values not comparable unless all measurement conditions are the same (Temperature, humidity, measurement duration, ...)
- Measurement limits of the commercially available devices are not sufficient to report the exact values
- Limitation of measurement capacity, when using commercially available devices for permeation ➔ Long measurement times

High Barrier Performance Measurements for VIPs

Gas and Water Vapor Barrier Performance

Permeation measurements through

1) Flat films: VIP laminates <u>before</u> VIP production
2) VIP envelopes: VIP laminates <u>after</u> VIP production



Schematic cross-sectional view of a „cut" VIP

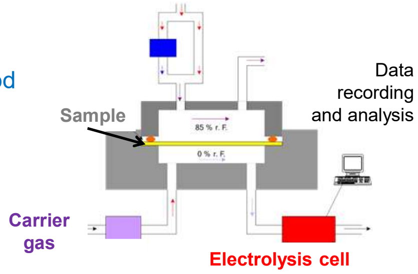
Permeation Measurement Techniques and Conditions

Flat Film Measurements by Coulometric Method

Water Vapor Transmission Rate (WVTR)

Mocon® Aquatran™ Model 2

- DIN EN ISO 15106-3
- Measurement limit: 5×10^{-5} g / ($m^2 \cdot$day)
- Sample area: 50 cm^2
- Temperature: 40°C, RH: 90%
- Pre-conditioning: 2 days, 60°C, 0.5 mbar



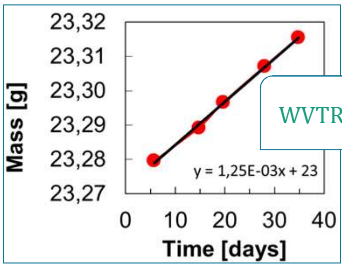
Permeation Measurement Techniques and Conditions

VIP Envelopes

WVTR by Water Intake (Gravimetric)

- TC 88 WG 11 “VIP for buildings”
- Measurement limit: 2×10^{-3} g / ($m^2 \cdot$day)
- Temperature: 40 °C, RH: 90%

Climate chamber



$$\text{WVTR} = \frac{\Delta m\ (g)}{\Delta t\ (days) \times Area\ (m^2)}$$

Micro-balance

Permeation Measurement Techniques and Conditions

WVTR Measurement Conditions - Summary

Laboratory	Flat Films	Measurement conditions
Lab-1	**MOCON® Aquatran™ Model 2** Meas. Limit: 5×10^{-5} g/(m²·d)	**40 °C / 90 % RH**

Laboratory	VIP Envelopes	Measurement conditions
Lab-2	**Water Intake (Gravimetric)** Desiccant (~ 150 mm x 120 mm x 5 mm)	**40 °C / 90 % RH**

Water Vapor Transmission Rate (WVTR)

Measurement Results - Summary

Sample Type	Flat films	VIP Envelopes
	Lab-1	Lab-2
	@ 38°C / 90% RH g / (m²·day)	
Bi-laminate	1.5×10^{-2}	3.0×10^{-2}
Tri-Laminate	2.1×10^{-2}	1.7×10^{-2}

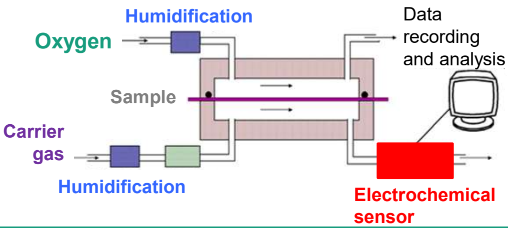
Permeation Measurement Techniques and Conditions

Flat Film Measurements by Coulometric Method

O_2 Permeability

Mocon® Oxtran® Model 2/21

- DIN 53 380, T3
- Measurement limit: 5 × 10^{-3} cc(STP) / (m^2·day·bar)
- Sample area: ~ 50 cm^2
- Temperature: 23 °C, RH: 50%



Conclusions and Outlook

- **No significant influence** of VIP production on **water vapor barrier performance** of laminates; similar results for flat films and VIP envelopes
- Comparison of **O_2 permeability** of the **flat films** to the **air permeability** values through **VIP envelopes into the VIPs** only by **rough estimation**
- **Air permeability** measurements using **VIP thermal conductivity** change as a function of time proves to be a very promising method
- **European Committee for Standardisaton** (CEN) is currently working on the adoption of some of the techniques used within this exercise
- **Further work** still necessary to relate the **real lifetime of VIPs** to **gas/water vapor barrier** properties**!**

Outline

- Barrier requirements of various products
- Gas permeation through polymers
- High barrier films: Production, permeation mechanisms, challenges
- Barrier performance measurements
- Results from collaborative projects
- Summary and outlook

Summary and Outlook

- **High barrier requirements** of products can be fulfilled by structures of alternating inorganic and polymeric layers
- **Permeation through inorganic layers** limited to defects (pinholes, cracks).
- Barrier performance of multilayer films due to **synergistic effect, tortuous path effect and extended lag time**
- Further barrier improvement possible by **lamination,** and / or integration of **water vapor absorbers**
- **Modelling and numerical simulation** help to optimize barrier film structures
- **Characterisation: Permeability measurements**

  New high sensitive WVTR measurement techniques

Summary and Outlook

Requirements for barrier films depend on final application…

Multi-disciplinary approach for successful development

Close cooperation with end-product producers!

- **Low cost deposition techniques, roll-to-roll and large area production:**
  High rate evaporation processes combined with lamination
- **Climate stability (weatherability) for outdoor applications:**
  UV- stabilised and hydrolysis resistant substrates
- **Compatibility to subsequent processes and added functionality:**
  Ready-to-use encapsulation films with adhesives
- **Mechanical stability, adhesion** between layers **crucial**
  Adhesion promoting tie-layers

Thank you for your interest!

www.ivv.fraunhofer.de

ANNEX II

Barrier Materials in Flexible Packaging for Food Applications

Fraunhofer Institut for Process Engineering and Packaging, Freising

BARRIER MATERIALS IN FLEXIBLE PACKAGING FOR FOOD APPLICATIONS

Fraunhofer Institut for Process
Engineering and Packaging (IVV) - Freising

Fraunhofer IVV

Joseph von Fraunhofer (1787 – 1826)


© Deutsches Museum

- **Researcher**
  - discovery of the "Fraunhofer lines" in the solar spectrum
- **Inventor**
  - new methods for processing lenses
- **Entrepreneur**
  - director and partner in a glassworks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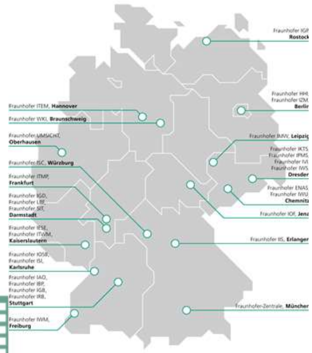
The Fraunhofer-Gesellschaft at a Glance

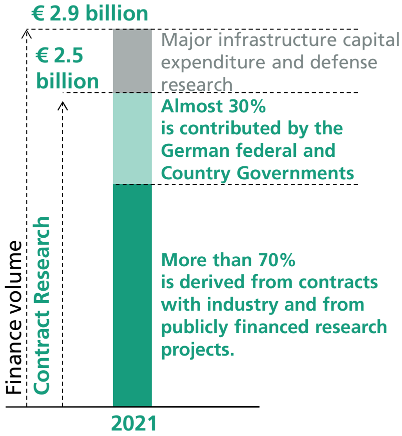
FLEX FUNCTION 2 SUSTAIN

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society.

30 028 staff



76 institutes and research units



Fraunhofer IVV

Fraunhofer-Gesellschaft Worldwide

FLEX FUNCTION 2 SUSTAIN

Fraunhofer IVV

FRAUNHOFER INSTITUTE FOR PROCESS ENGINEERING AND PACKAGING IVV

www.ivv.fraunhofer.de

Fraunhofer IVV – Location Freising – Location Dresden

Institute Head Fraunhofer IVV: Prof. Dr. Andrea Büttner | Prof. Dr.-Ing. Jens-Peter Majschak

- Total workforce 269
- Scientists and graduates 143
- Postgraduate students 36

Total Budget € 22,2 million

(Status April 2021)

Total workforce 56
Scientists and graduates 41
Postgraduate students 5

Total Budget € 4,7 million

(Stand: 2021)

Possible Forms of Collaboration

Publicly funded projects

- Contributions of the companies to the project usually in the form of services, rarely money
- Pre-competitive research possible
- Project results publicly accessible

Bilateral projects

- Offer drawn up to meet the precise needs of the commissioning party
- Project starts immediately after the research is commissioned
- Project results exclusively for the commissioning party
- Confidentiality assured

Fraunhofer IVV

Our Business Fields and Core Areas of Expertise

Food
High-quality, healthy and convenient foods and ingredients

Packaging
Safe, customer-friendly and recyclabel packaging materials

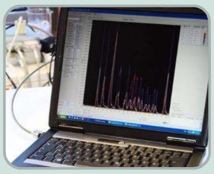
Processing Machinery
Optimized production and cleaning processes and digital solutions for Industry 4.0

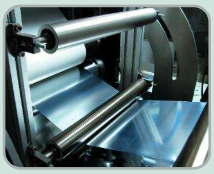
Product Performance
Holistic sensory optimization of raw materials and market-ready products

Recycling and Environment
Innovative recycling technologies, bio-based additives and environmental analysis

Fraunhofer IVV

Material Development – who we are





Functional Materials
Development of films with barrier properties specially adapted to your requirements

Biobased Materials
Development of bio- and fiber-based materials and packaging

Shelf-Life Modelling
Predicting the shelf life of products in new packaging and optimizing packaging

Packaging pilot plant
Product optimization on a pilot scale with low amount of materials/ test processability of new materials and material combinations

Packaging Lab
Evaluation of mechanical and optical parameters as well as permeability as an elementary component of your material development and quality assurance

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AGENDA

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Packaging Requirements and Packaging Materials: Shelf life

„Fresh“

Handling
Packing
Transport
Storage

Decay of quality

Still „fresh“

Spoiled

Producer

Consumer

Fraunhofer IVV

Packaging Requirements and Packaging Materials: Shelf Life

Deterioration reactions of filled goods

- Microbial processes
  - Aerobic processes: oxygen
  - Anaerobic processes: without oxygen
- Chemical / biochemical processes
  - Fat oxidation: light influence, oxygen
  - Enzymatic browning : oxygen
- Physical processes
  - Loss of flavour
  - Water loss, water absorption

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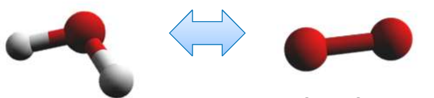
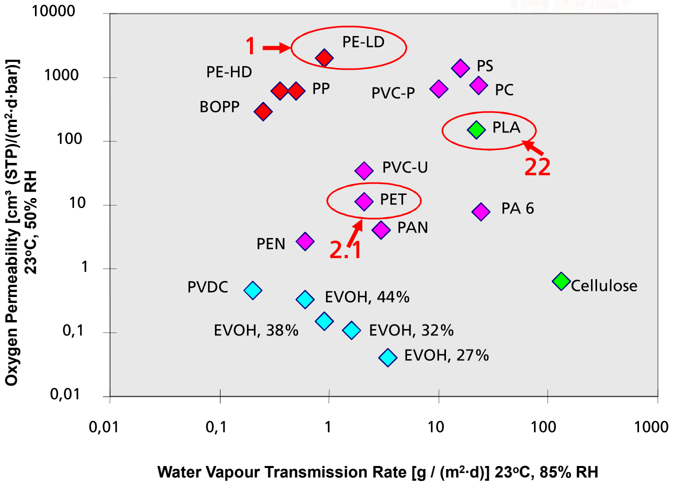
Packaging Requirements and Packaging Materials: WVTR and OTR

At 23°C and 50% RH conditions



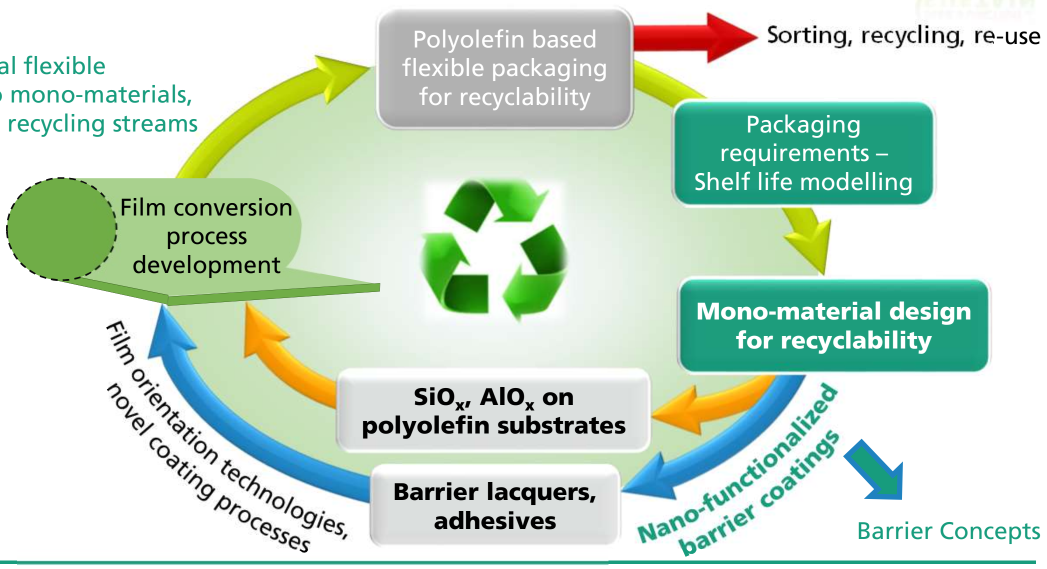
WVTR - Water Vapor Transmission Rate	OTR – Oxygen Transmission Rate
1 g/(m²d)	1 cm3/(m²d bar)



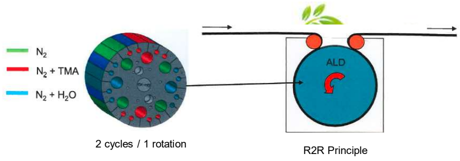
- The shelf life of water in a **PET** bottle would be about **10 times longer** than in a **PLA** bottle
- The shelf life of a dry product would be **22 times shorter** in **PLA** than in **PE-LD** of the same thickness

Design for Recycling

Redesign
multi-material flexible
packaging to mono-materials,
with existing recycling streams



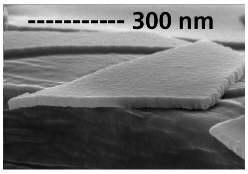
Barrier Concepts: „Mono-material“ Multi-layer



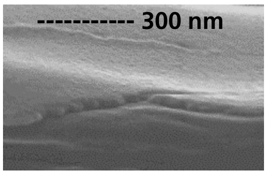
Atomic Layer Deposition
(Source Fraunhofer IVV)

Upgrade in 2023
FlexFunction2Sustain
Grant Agreement ID: 862156

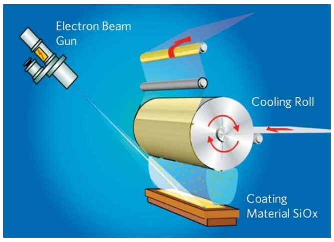
- **Thin Inorganic Layers on Polyolefin Substrates with Primer Coating**
  - Physical Vapor Deposition (PVD)
    - Thermal or electron beam evaporation
  - Inorganic barrier materials
    - Transparent oxides (e.g. SiO_x, AlO_x), Al, …
- Substrates: PET, BOPP, …



SiO_x (~ 60 nm)



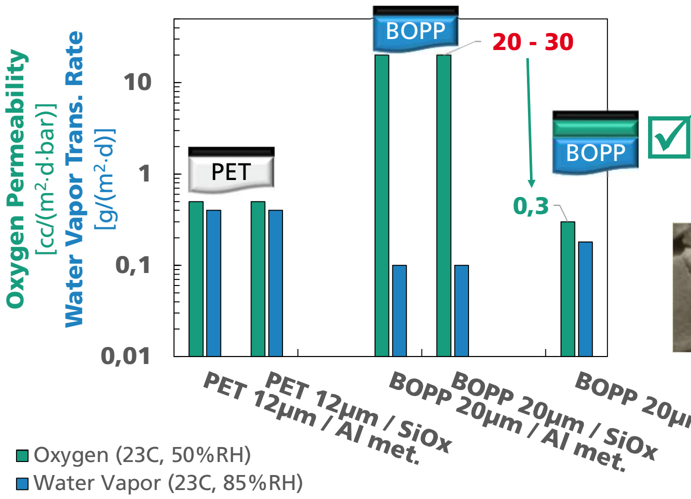
Al metallisation (~ 50 nm)

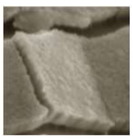


Electron beam evaporation
(Source: Amcor Flexibles)

Barrier Concepts: „Mono-material“ Multi-layer

- **Thin Inorganic Layers on Polyolefin Substrates with Primer Coating: Results**





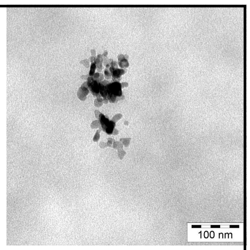
Substrate surface topography
Layer chemical composition

Deposition process
Growing inorganic layer

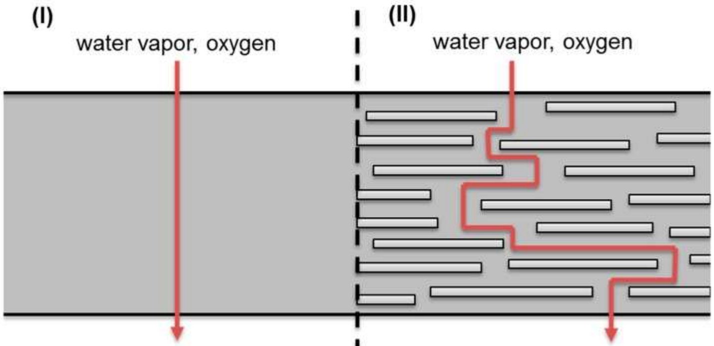
Reduction in macroscopic defects

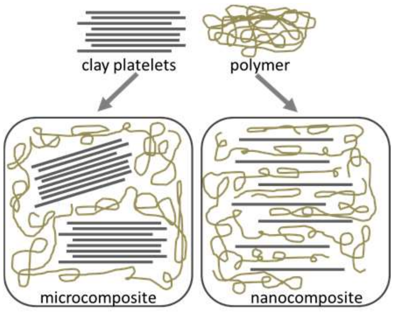
Oxygen barrier

Barrier Concepts: „Mono-material“ Multi-layer



- **Nano-composite Coatings**



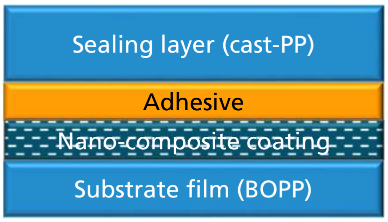


"**Tortuous pathway**" by exfoliated clay **nano-platelets** in a polymer

K. Müller et al., Nanomaterials (Basel). 2017 Apr; 7(4): 74

Barrier Concepts: „Mono-material“ Multi-layer

- **Nano-composite Coatings: Biggest Challenges**
  - Homogeneous dispersion for good surface properties and transparency
  - Exfoliation of nanoparticles for nano-metric thickness of platelets and maximum possible surface
  - Orientation of platelets for gas barrier → Alignment by shearing during coating

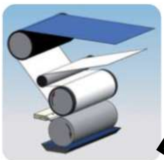


☑ **Designed for Recycling: > 90% Polyolefin „Mono-material“ Multi-layer**

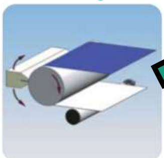
Barriflex - Enhanced Performance of Flexible Plastic Materials by Innovative Nanotechnologies for Food Packaging and Technical Applications (2019-2020)

Barrier Concepts: „Mono-material“ Multi-layer

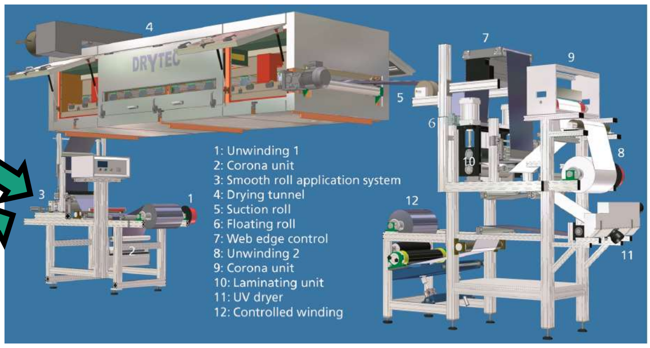
- **Nano-composite Coatings: Biggest Challenges**

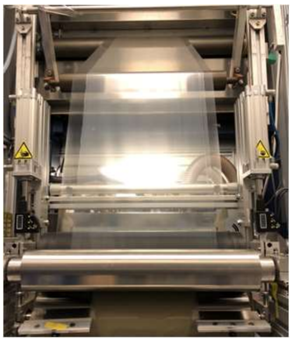


Reverse gravure



Slot-die





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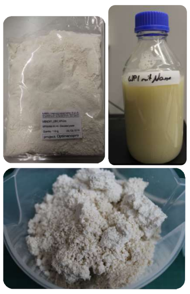
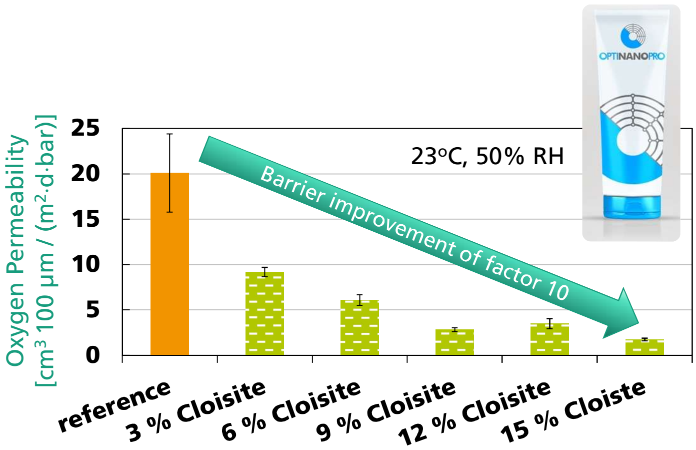
Barrier Concepts: „Mono-material“ Multi-layer

- **Nano-composite Coatings: Results**



Montmorillonite (Cloisite Na+)

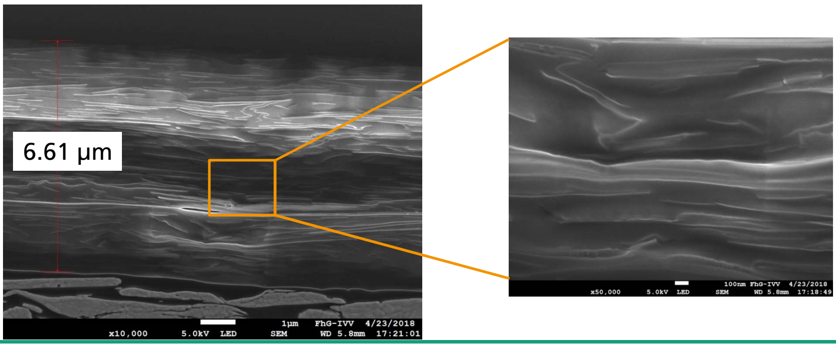


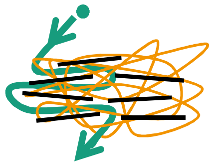
OPTINANOPRO N. Brzosoka, E. Kucukpinar et al., Polymers **2019**, 11, 1410

Fraunhofer IVV

Barrier Concepts: „Mono-material“ Multi-layer

- **Nano-composite Coatings: Results**
  - Exfoliation of nanoplatelets in Wheylayer ➔ Orientation during coating process
  - Roll-to-roll reverse gravure pilot coatings and process optimisation





Tortuosity effect maximised by optimal dispersion and orientation

Summary and Outlook

- Requirement: Designing products and packaging for recyclability
- Challenges and Solutions:
  - Mono-material based multi-layers: Polyolefin (BOPE, BOPP) based packaging systems are more feasible due to their proven sorting and recycling technologies at industrial scale
  - Low oxygen barrier performance: Nano-functionalisation enhances the barrier!
    - Nanocomposite coatings increase the oxygen barrier performance and make it possible to use the polyolefin based „Mono-material“ Multi-layers for flexible packaging
    - Fraunhofer IVV has the required coating processes and analytics for the application of functional barrier coatings, including exfoliation and orientation of the nano-particles
- Next Steps: Further production of novel mono-material multi-layers with other types of substrates, and shelf-life tests for sensitive food products

„Thank you“ for making plastics sustainable!

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ANNEX III

Food Compliance in the EU

INL - International Iberian Nanotechnology Laboratory, Braga

Food Contact Compliance in the EU

- The Food Contact Material's Regulatory landscape in the EU
- Framework Regulation (EC) No 1935/2004 on Food Contact Materials
- Regulation (EC) No 2023/2006 on Good Manufacturing Practice (GMP)
- Regulation (EU) No 10/2011 on Plastic Food Contact Materials
    - Scope
    - Union List of authorised substances for FCMs
    - Testing for Compliance
- Preparation of a Declaration of Compliance (DoC)
- Non-Harmonized Legislation
- Steps to Achieving Compliance in the EU

ANNEX IV

JOA’s R2R Nano-patterning Processes and Offered expertise

JOANNEUM RESEARCH, Graz

JOA’s R2R nano-patterning processes and offered expertise

	JOANNEUM RESEARCH is a non-profit research institute headquartered in Graz (Austria). At the institute “Materials”, located in Weiz, cutting edge technologies and methods that are based on miniaturization, integration and materials optimization are used.
	In the photolithography process, light is used to transfer a geometric pattern through a mask to a photosensitive resist on a substrate. The main limitation of this method is the wavelength of the used light, which imposes the geometrical size of fabricated structures - hence only structures down to 1µm are possible. A higher resolution is gained by means of **nanoimprint lithography**. Here, a geometric pattern is created by the mechanical deformation of the imprint resist. That means, a patterned stamp is pressed into the liquid resin and the resin is then hardened either by UV light or heat. Hence, the nanoimprint lithography is an advanced method for creating patterns down to the nanometer range at a low cost.
	At Joanneum Research Materials in Weiz, the nanoimprint lithography process is **up-scaled in a R2R-nanoimprint-machine**. With this machine it is possible, to continuously produce large-area flexible, patterned substrates at low cost. In this video, the continuous R2R process is shown:
	First, a flexible plastic film substrate is coated with a UV curable resin. Then, the coated substrate is guided to the imprinting station. Here a stamp (also called shim) with the desired surface pattern is pressed into the liquid resin. The shim is usually a nickel or polymer sheet with excellent anti-sticking properties which is wrapped around the imprinting roller. During the whole contact time between the stamp and the resin, the resin hardens by UV light. Finally, the substrate with the imprint is demolded form the stamp and wound up.
	One key prerequisite is the adjustability of the imprint resin towards the targeted application scenario. At Joanneum Research Materials diverse **UV-curable resins** that are mainly based on polyurethane acrylates are developed. This NILcure® resin portfolio offers a wide range of possibilities, and the resin can be tailored in terms of mechanical, chemical and optical properties.
	These chemically adjusted structured foils achieve for instance drag reducing surfaces, antireflecting or hydrophobic surfaces. Or the foils can just be decorative or used in the lighting sector when they are structured with micro-optics.
	The expertise offered by Joanneum Research Materials, as member of the ESNA association, includes: • **UV- imprint resin (NILcure®) formulation and testing**. In particular, formulation and batch/R2R testing of tailored imprint and UV resins. Tailoring of mechanical (e.g. elasticity), optical (e.g. refractive index), surface chemical (e.g. hydrophilicity/hydrophobicity) and reliability (e.g. weathering resistance) properties. • **R2R-micro/nanoimprinting**. In particular, nano- and micro (optical) structuring of PET, recycled PET, and cellulose based surfaces by the use of R2R UV-NIL machines with inline quality and process control. Applications include Optical films, Security features, Freeform micro-optics, Lighting, Displays & Photovoltaics, 3D printing, Microfluidics, Point-of-Care diagnostics, Lab-on-Foil, Biomimetic/bionic structures. • **Micro/Nano characterization.** In particular, characterization of materials and structures on the micro/nanoscale (surface, volume-cross sections): Keyence 3D laser scanning microscopy, AFM, SEM, XPS, etc.

ANNEX V

Flexible Organic and Printed Electronics from Lab to Fab

Aristotle University of Thessaloniki

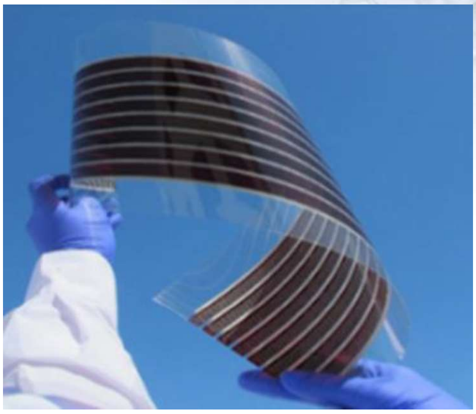
Flexible Organic & Printed Electronics from Lab to Fab

S. LOGOTHETIDIS, S. KASSAVETIS, A. LASKARAKIS, Ch. KAPNOPOULOS, Ch. GRAVALIDIS

Nanotechnology Lab LTFN
Aristotle University of Thessaloniki,
Thessaloniki, K. Makedonia, GR-54124, Greece

Content

Content
- Printing Techniques for Lab-Scale Organic Photovoltaics
- Upscaling in Sheet-to-Sheet (S2S) pilot line
- Upscaling in Roll-to-Roll (R2R) pilot line
- Summary



Flexible Printed Electronics Devices From Lab to Fab

R2R Compatible NanoMaterials Printing: Slot-die, Gravure Printing, InkJet Printing

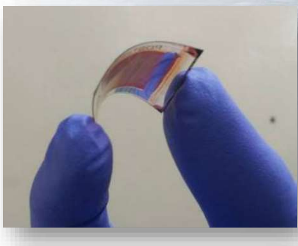
Characterization of Materials: Surface, Optical, Chemical, Mechanical

Device Testing: Performance, Lifetime, Stability

Upscaling to R2R pilot production
Printing: Slot-Die, Rotary Screen Printing
Materials Pattering / Scribing: ps-Laser Patterning - Free form Devices
Surface Nanopatterning: R2R UV-Nanoimprint Lithography
Inline Process Monitoring

Large Scale Device Testing: Performance, Lifetime, Stability

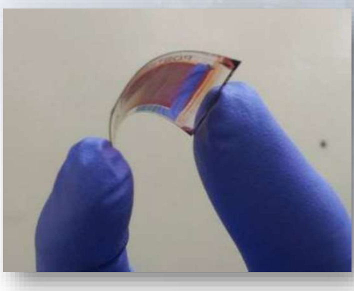
Lab Scale Device



Pilot Product

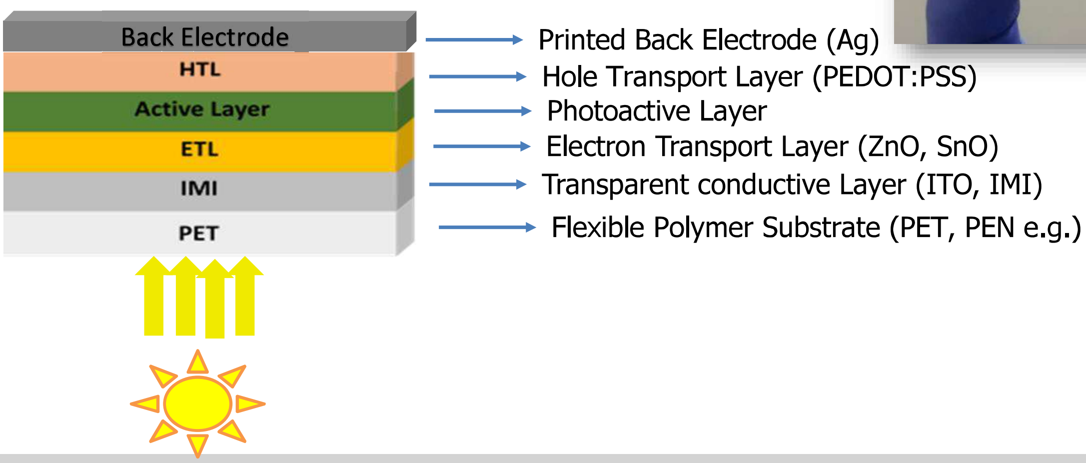
Organic & Printed Electronics from Lab to Fab

Digital fabrication of OEs & Bioelectronics nanomaterials, devices and systems



Flexible Printed Organic Photovoltaics

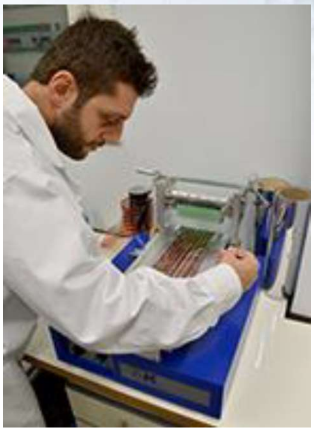
- Inverted Structure



Organic & Printed Electronics from Lab to Fab

Digital fabrication of OEs & Bioelectronics nanomaterials, devices and systems

Printing techniques



Screen Printing : The pattern is printed by filling the screen with an emulsion that is impervious to the coating solution in the areas where no print should appear.

The area of the printed pattern is kept open (without emulsion). The screen is then filled with coating solution and brought into proximity of the substrate.

The thickness d of the printed film is given by:

$$d = V_{sreen}\, k_p\, c/p$$

where $\mathbf{V_{screen}}$ is the paste volume of the screen,
$\mathbf{k_p}$ is the pick-out ratio,
c is the material concetration in the ink (gr/cm^3) and
p is the dry-film density (gr/cm^3)

Organic & Printed Electronics from Lab to Fab

Digital fabrication of OEs & Bioelectronics nanomaterials, devices and systems

Printing techniques

Ink-Jet Printing : Mechanical compression of the ink through a nozzle (piezoelectric) or by heating the ink (and thus creating a pressure increase).
Droplets are electrostatically charged and accelerated towards the substrate by an electric field.

The thickness d of the printed film is given by:

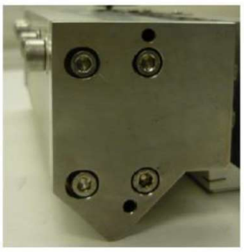
$$d = N_d\, V_d\, c/p$$

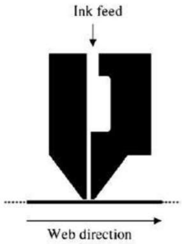
where **Nd: No of droplets per are (cm^{-2})**
$\mathbf{V_d}$ Volume of droplets,
$\mathbf{k_p}$ is the pick-out ratio,
c is the material concetration in the ink (gr/cm^3) and
p is the dry-film density (gr/cm^3)

Digital fabrication of OEs & Bioelectronics nanomaterials, devices and systems

Printing techniques

Slot Die Coating: Printing of stripes of material. Suitable for multilayer devices such as solar cell with overlapping stripes of different materials The inks are feed to the Slot die head with a pump or a pressure system.





The thickness d of the printed film is given by: $d = \frac{f}{S_w}\frac{c}{p}$

where **f:** Flow rate ($cm^3\ min^{-1}$)
S_w Coated width (cm),
c is the material concetration in the ink (gr/cm^3) and
p is the dry-film density (gr/cm^3)

Upscaling on Sheet2Sheet Pilot line:

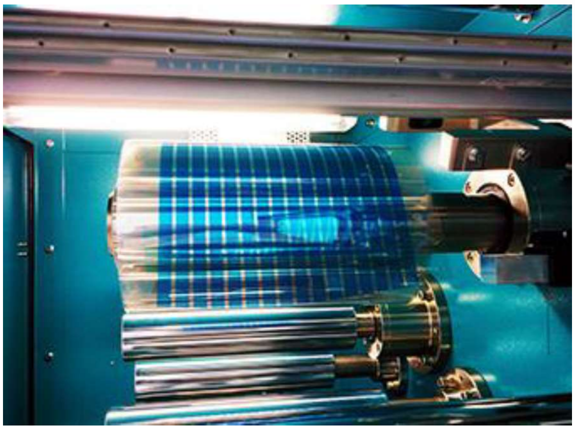
Hybrid Printing and Vacuum technologies for OE devices with Encapsulation technologies and

Solar Simulator for measuring the efficiency of Solar Cells and Organic Photovoltaics Modules

Organic & Printed Electronics from Lab to Fab

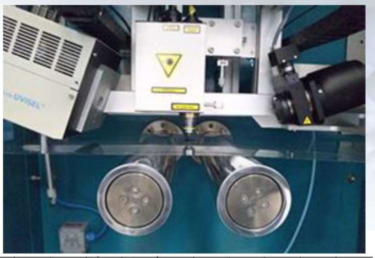
Upscaling to the manufacturing of pilot products

R2R Pilot-to-Production Line: Large area R2R manufacturing of Organic Electronic devices
Printing technologies: Slot-Die, Inkjet, Screen printing
In-line NanoPattening/Scribing Techniques: Ultra-fast Picosecond Laser Patterning, UV-NanoImprint Lithography
In-line metrology: Vis-UV Spectroscopic Ellipsometry, Raman Spectroscopy
Encapsulation of Devices



Organic & Printed Electronics from Lab to Fab

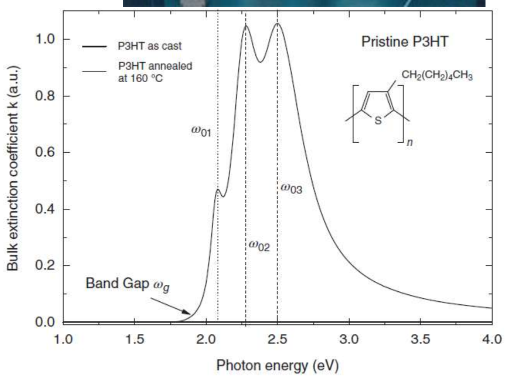
Inline nIR-Vis-UV Spectroscopic Ellipsometer



Inline Phase Modulated Spectroscopic Ellipsometer (0.6 – 6.5 eV)
Thickness measurement (subnanometer resolution), optical properties (n, k), optical band gap, interface and roughness thickness, film composition and uniformity in depth and area.

- **Description / specification table :**
  - Substrates: Glass, Polymer, Paper
  - Sample Processing Range: up to 30 x 30 cm
  - Measuring Range / Conditions: 0.6-6.5 eV / RT,

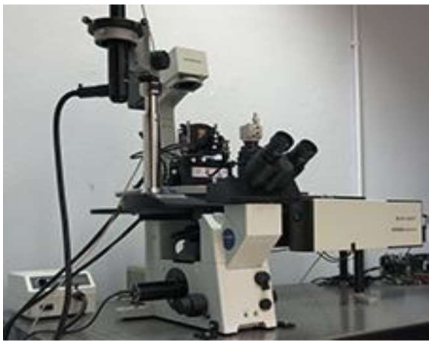
- **Use / Application examples :** Surface and thin film optical characterization, Printed Electronics, Semiconductors, dielectrics, polymers, organics, and metals

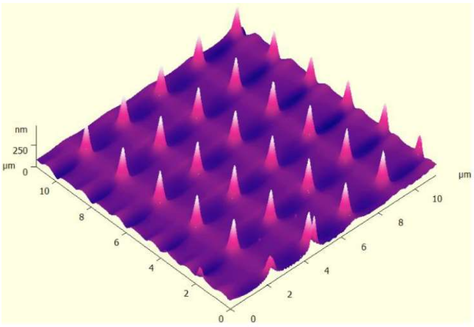


Calculated extinction coefficient (k) of pristine P3HT as a function of the annealing temperature after the analysis of the measured $\langle\varepsilon(\omega)\rangle$ spectra.

Intelligent Roll-to-Roll Manufacturing of Organic Electronic Devices, **Stergios Logothetidis, Argiris Laskarakis**
Chapter in Solution-Processable Components for Organic Electronic Devices, Wiley Online Books
https://doi.org/10.1002/9783527813872.ch12

Organic & Printed Electronics from Lab to Fab





Surface Characterisation by Scanning Probe Microscopy

Scanning Probe Microscope (SPM) platforms for surface, Raman and Nano-mechanical characterization of nanomaterials (thin films, polymers, nanoparticles etc.) and Nano systems. The SPM platform supports:

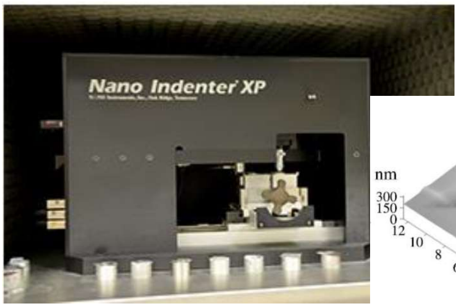
- Atomic Force Microscope scanning in Contact, Tapping and non-Contact modes
- Scanning Tunnelling Microscopy
- Scanning Near-Field Optical Microscopy (532 nm Laser source)
- Atomic Force Acoustic Microscopy (Surface mechanical properties)
- Scanning in Liquid head and nitrogen environment
- Heating Stage (up to 300 ºC)

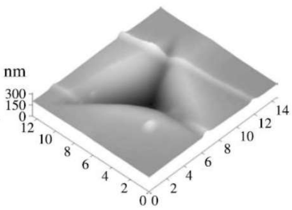
Description / specification table :

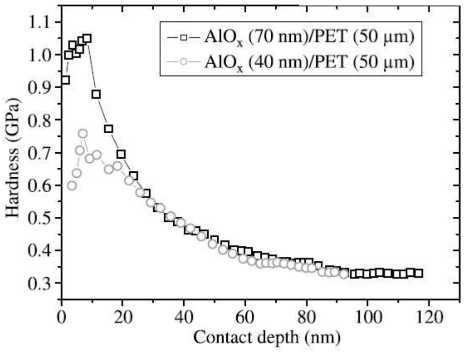
- Substrates: Glass, Polymer, Paper
- Sample Processing Range: up to 50 mm x 50 mm
- Measuring Range / Conditions: 100 x 100 µm Scanning Surface Area

Use / Application examples : Surface Characterisation, Nanoparticles characterization, Printed electronics, Organic Photovoltaics (OPVs)

Organic & Printed Electronics from Lab to Fab







Hardness of a AlO protective layer on top on PET substrate

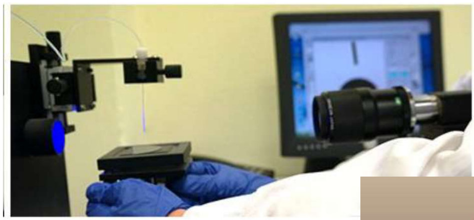
Nanomechanical Characterisation Nano Indenter XP / Scratch Tester

Nano-indentation and Scratch Testing apparatus for quasi-static and dynamic nano-mechanical characterisation **(Hardness, Elastic Modulus, Adhesion, Friction) of surfaces, soft (polymers) and hard thin films and bulk materials**.

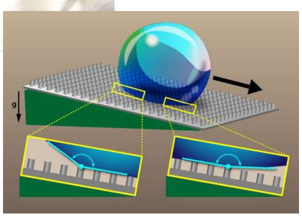
- **Description / specification table :**
  - Substrates: Various (Glass, Polymer, Paper)
  - Sample Processing Range: up to 50 mm x 50 mm
  - Measuring Range / Conditions: 100 mN maximum applied load, 20 µN lower normal applied load
- **Use / Application examples :** Nano indentation and Scratch Tests of bulk materials, nanocomposite materials, hard protective coatings and thin films, barrier coating for flexible electronics packaging, soft materials (polymers and organic layers) fibrous scaffolds, nanocomposite concrete.

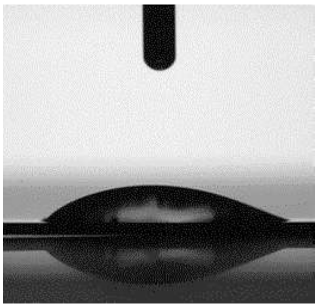
Nanomechanical Testing of the Barrier Thin Film Adhesion to a Flexible Polymer Substrate, S. Kassavetis, , S. Logothetidis, & I. Zyganitidis, Journal of Adhesion Science and Technology Volume 26, 2012 - Issue 20-21: Adhesion Aspects in Packaging, https://www.tandfonline.com/doi/full/10.1163/156856111X599526

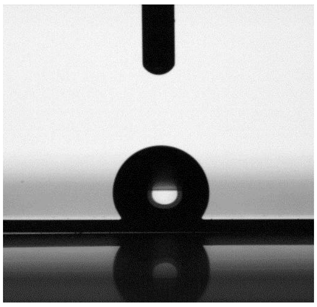
Nanotechnology Lab LTFN: SERVICES for SMEs & Start-Ups



Superhydrophilic & Superhydrophobic Surfaces







Contact Angle System

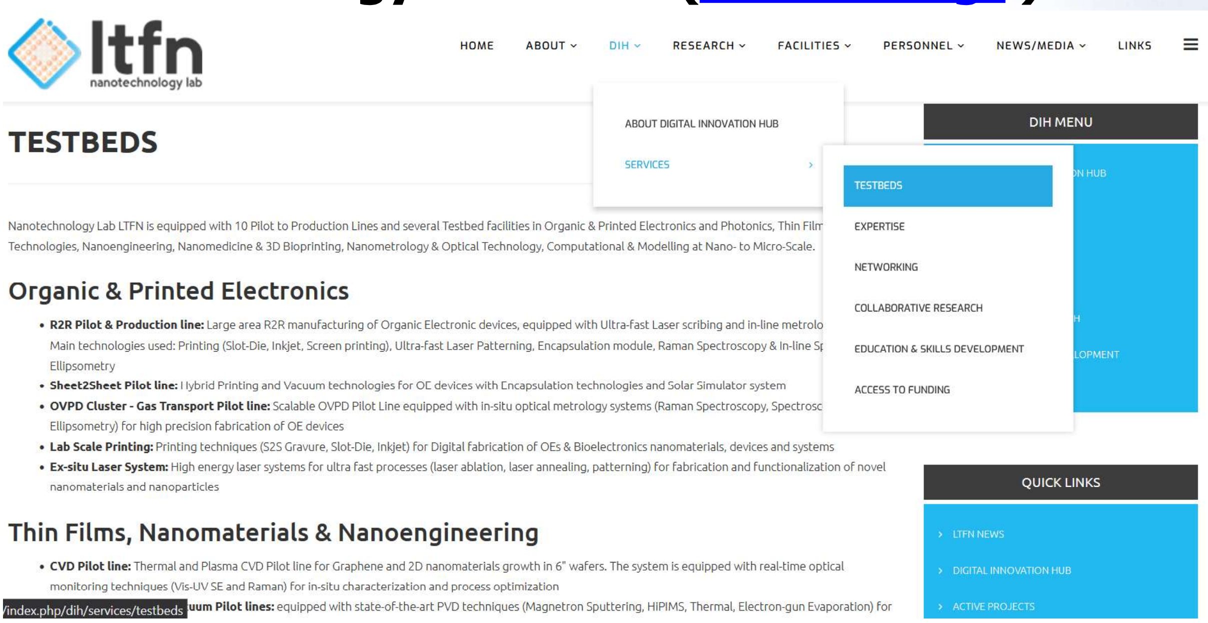
for measuring contact angle and free surface energy. A CCD firewire camera (512x480) with telecentric zoom optics combined with LED based background lighting allows capturing images (image area 5.7 x 5.4 mm2) at frame intervals from 10 ms to 1000s.

• **Description / specification table :**
- Sample Processing Range: 150x50 mm
- Measuring Range / Conditions:
  - 0 - 180o degrees
  - Frame interval: 40ms - 1000s
  - Inaccuracy: +/- 5 degrees
  - Curve fitting to Young Laplace equation, cycle, polynomial and Bashforth/Adams

• **Use / Application examples :** Determination of surface or interfacial tension, contact angles, absorption or surface free energy of :
- Surfactants & Detergents, Emulsions
- Polymers, Papers, Films & Inks, Substrates
- Sprays, Paints & Coatings

Organic & Printed Electronics from Lab to Fab

Nanotechnology Lab LTFN (www.ltfn.gr)



Flexible Organic & Printed Electronics from Lab to Fab

S. LOGOTHETIDIS, S. KASSAVETIS, A. LASKARAKIS, Ch. KAPNOPOULOS, Ch. GRAVALIDIS

Nanotechnology Lab LTFN
Aristotle University of Thessaloniki,
Thessaloniki, K. Makedonia, GR-54124, Greece

ANNEX VI

Mechanical Recycling for Flexible Plastics

Centre Technique Industriel
de la Plasturgie et des Composites, Bellignat

Centre Technique Industriel
de la Plasturgie et des Composites

Faire aboutir ensemble
Vos projets d'innovation
Plastiques et Composites.

Technical teaching course

Mechanical recycling for flexible plastics

ct-ipc.com

INSTITUT CARNOT Ingénierie@Lyon

Recycling, what is it ?

Definition

'Recycling' means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

Article 3(17), Waste Framework Directive

Packaging recyclability, what is it ?

Definition

A global definition of "recyclability" was developed by The Association of Plastics Recyclers (APR) and Plastics Recyclers Europe (PRE) in 2018.

4 conditions are required for a packaging to be considered as "recyclable" :

- The product must be made **of plastic that is collected** for recycling, has market value, and/or is supported by a legislatively mandated program.
- The product must **be sorted and aggregated into defined streams** for recycling processes.
- The product **can be processed and reclaimed/recycled** with commercial recycling processes.
- The recycled plastic becomes a raw material that **is used in the production of new products**.

***Source**: Recyclass website, https://recyclass.eu/recyclability/definition/*

Recycling technologies

Recycling technologies can be classified under two categories:

IPC

Mechanical recycling

Selective dissolution

Physical Recycling

Technologies and processes whereby plastic waste materials are recycled back into plastics without altering the chemical structure of the materials.

Chemical Recycling

Technologies and processes whereby clean plastic streams undergo a chemical process which includes a purification step, to potentially obtain virgin-like polymers to be used in new plastic articles.

Pyrolysis

Gasification

Hydro-cracking

Depolymerisation

Selective dissolution

***Source**: PRE website, https://www.plasticsrecyclers.eu/plastic-recycling/how/*

A complete service offer at IPC

MATERIAL SELECTION

- Materials substitution or research
- Materials comparison

FORMULATION AND COMPOUNDING

- Specific formulations development
- Integration of additives, reinforcements…
- Sampling from some kilograms to tons
- Post-consuming or post-production regeneration
- Standardized samples, injection, lab testing and analysis

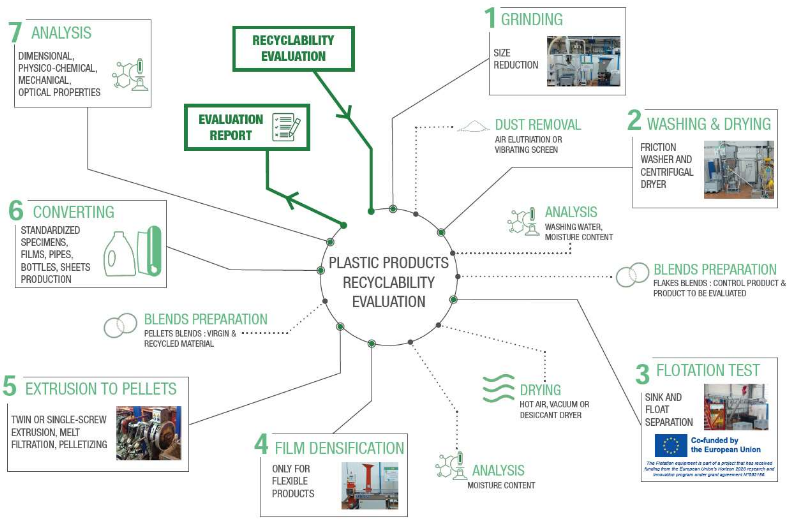
RECYCLABILITY EVALUATION

- Rigid and films// Commodities (PE, PP) or technical (PA, PPS, PEEK…)
- Material preparation (sorting, grinding), washing, densification, granulation, filtration, post-transformation, characterization
- Recyclability evaluation based on protocols (RecyClass, COTREP…)

EXTRUSION PROCESS

- Profiles, films, sheets, plates, containers…

Mechanical recycling at IPC



DIS30 est co-financée par l'UE (fonds FEDER), et soutenue financièrement par la région Auvergne-Rhône-Alpes.

A unique recycling line in France : **REMIX pilot line**

Objectives:

- Give access to a technological platform that is representative of industrial means.
- Evaluate recyclability for both flexible and rigid plastic products
- A modular and upgradable pilot line to address different kind of materials

Evaluation process:

- Reproduction on a pilot scale of sorting and treatment of plastic waste (grinding, washing, sifting, metallic parts removal, drying, sorting)
- Regeneration and formulation (compounding, compatibilization, reactive extrusion / Custom formulation to meet specifications)
- Injection and extrusion process (profiles, plates, films, containers,..)

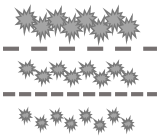
REMIX : Size reduction, sorting and washing unit

Knives grinding unit
(Rigid Materials)
5 mm Grid

Shredder
(Flexible materials)
Grilles 10, 20, 30 mm

2 Grids vibrating sieve

> 10mm
2 < X < 10mm
< 2mm



SOREMA Washing / drying unit

REMIX: Material separation - sorting

Density based separation

Flotation bath
(Static)

Flotation bath
(Dynamic with rollers)

Electrostatic separation

HAMOS KWS
(Ferrous / non ferrous materials separation)

REMIX: Homogenization and densification

Vertical or rotational mixer

WANNER densifier and granulator
(for flexible materials)

REMIX: Granulation / filtration

➢ Material homogeneization using lamination and filtration (filter size 500µm, 300µm, 150µm, 125µm…)

bi-vis extruder

Filtration unit

REMIX: Quality control (granulates / parts / samples)

➢ **Parts Production / test samples**

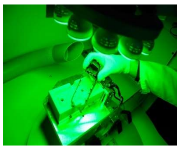
- Injection of standardized test samples
- Extrusion-inflation and et films extrusion
- Extrusion of profiles (tubes,..)
- Extrusion-blow molding of containers

REMIX: Laboratory evaluation on granulates, test samples

➢ **Physico-chemical characterization**
- Heavy metals detection
- Ash content
- Humidity rate
- Infrared analysis
- Rheological properties (MFI, viscocity…)
- Thermal properties (DSC, ATG,..)
- Optical properties

➢ **Mechanical characterization**
- Mechanical properties (tensile, bending, impact, tearing, perforation…)

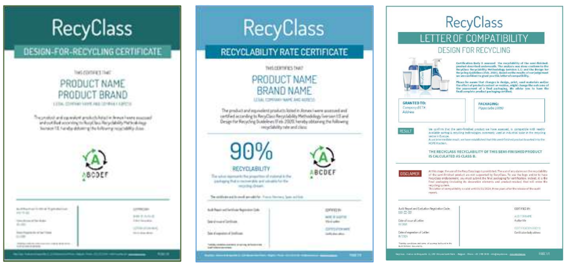




Recyclabilty certification

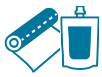
RecyClass

› IPC as **Recognized Certification Body** for **RecyClass** to **deliver certificates** based on an **audit of products**



› IPC as **Recognized Laboratory** for **Recyclability evaluation based on RecyClass** protocols on the following streams


HDPE containers & tubes (colored and transparent)


PE films (colored and natural)


PP containers & tubes (colored and transparent)


PP films (colored and natural)

Recycled content certification

LABORATOIRE NATIONAL DE MÉTROLOGIE ET D'ESSAIS

- **IPC and LNE** "French National Testing and Metrology Laboratory" **developed** in a joint effort a **certification scheme** that **assess the quantity of Recycled content incorporated** in products.
- This **certification scheme** has recently been **approved by PolyCert Europe**, **giving French industry access** to a certification scheme, compliant and **harmonized** with other **European** existing schemes
- This **certification scheme** consist of a **two part audit**:
  - Part 1: Global **RPM** (Recycled Plastic Materials) **quantity** used within a **production site**
  - Part 2: **Specific** quantities of **RPM contained** in a **product** / range of products

Company XXX has used 6750 tons of RPM in 2021	Contains 55 % of RPM

ANNEX VII

Life Cycle Assessment

Centre Technique Industriel
de la Plasturgie et des Composites, Bellignat

Centre Technique Industriel
de la Plasturgie et des Composites

**Faire aboutir ensemble
Vos projets d'innovation
Plastiques et Composites.**

Technical teaching course

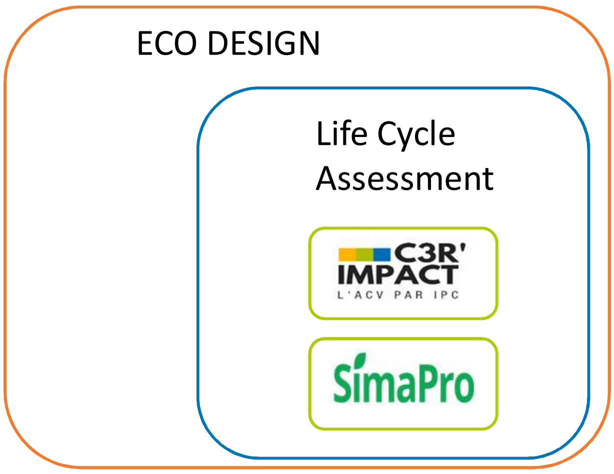
Life Cycle Assessment (LCA)

ct-ipc.com

INSTITUT CARNOT Ingénierie@Lyon

Life Cycle assessment, what is it ?

Definition



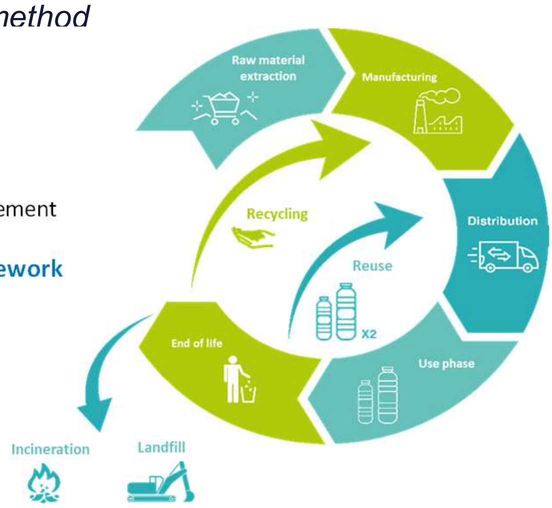
Eco Design: « taking the environment into account during the design or improvement phase of a product (good or service), by considering its entire life cycle »

LCA : «compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system over its life cycle »

Life Cycle assessment, what is it ?

A normalized method

ISO 14040 : 2006
Environmental management
life cycle assessment
principles and framework

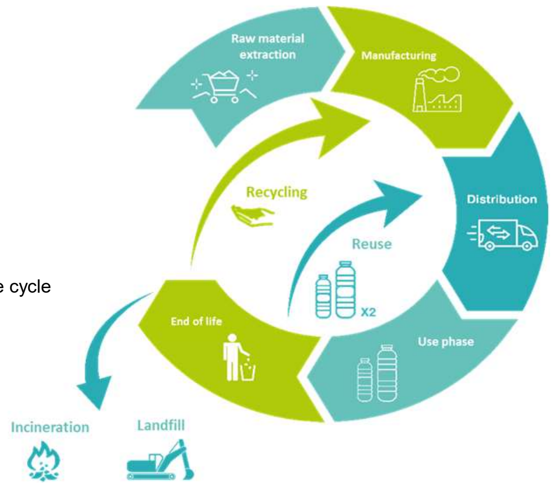


ISO 14044 : 2006
Environmental management
life cycle assessment
requirements and guidelines

Life Cycle assessment, what is it ?

A hollistic approach

1 – Multi-steps
Takes into account all life cycle stages

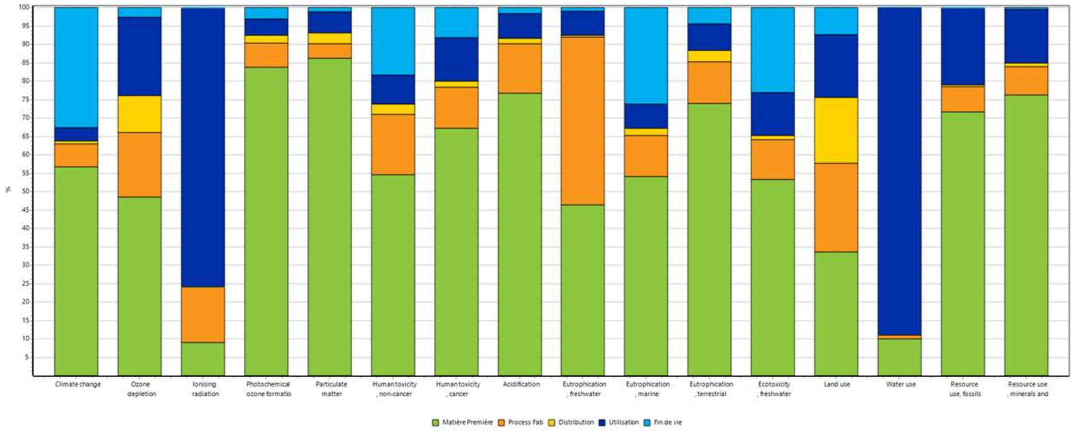


2 – Multi-indicators
Calculates impacts on several indicators to avoid impact shifting

3 – Multi-systems
takes into account the product's environment and its life cycle

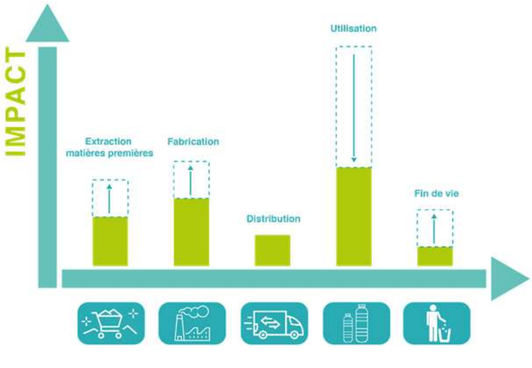
Why making an LCA ?

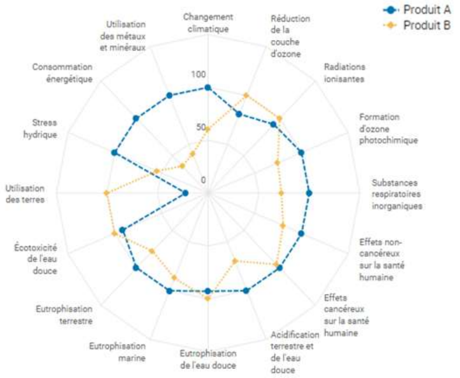
Identifying



Why making an LCA ?

Comparing and avoiding impact shifting





Why making an LCA ?

Communicating, using an Environmental Product Declaration

CRITICAL REVIEW

EPD®

FDES VÉRIFIÉE inies

PEP eco PASS PORT

srp

ECO-PROFIL des MPR
(MATIÈRES PREMIÈRES de RECYCLAGE)

R-PEHD Granulés

Mars 2020
(Annule et remplace celui de janvier 2017)

PRÉSENTATION

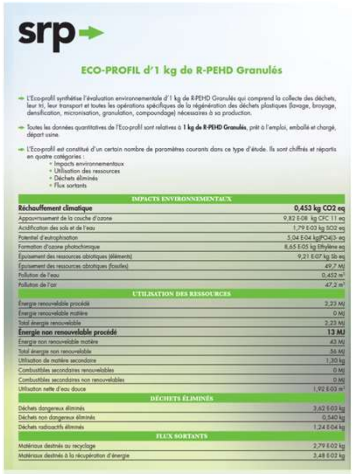
- **L'Eco-profil** proprement dit et les informations fournies ci-après sont extraits de l'étude* **"ICV des MPR"** diligentée par le SRP en 2016
  *Nota : À la date de diffusion du présent document sont disponibles sur le site du SRP :
  - La présentation de l'étude (7/03/2016)
  - Un glossaire
  - Les fichiers Excel justificatifs précédés par le rappel des principaux points méthodologiques
- Cette étude, menée conformément aux normes internationales (en particulier normes de la série ISO 14040), a fait l'objet d'une **revue critique externe*** par quatre experts indépendants garants de la qualité des informations fournies.
  *Nota : Le rapport de projet, les conclusions du comité de revue critique ainsi que les réponses du SRP sont consultables sur RV au siège du SRP.
- Cet Eco-profil a été établi à partir des informations portant, selon les sites, sur **les années 2015 (6 sites) et 2019 (1 site)**, transmises par les membres du SRP qui produisent cette matière première de recyclage (MPR) sur leurs sites de production situés en France métropolitaine :
  - CPA
  - ECOPLASTICS (Groupe VEOLIA-VPFR)
  - ENVIRONNEMENT MASSIF CENTRAL
  - GEROPLAST
  - PAPREC Plastiques 27
  - PAPREC Plastiques-MPB
  - PMG (Groupe VEOLIA-VPFR)
- Seuls les régénérateurs listés ci-dessus et leurs clients plasturgistes utilisateurs de cette MPR peuvent se prévaloir de cet Eco-profil et l'exploiter sans réserve.
- Toute exploitation partielle de cet Eco-profil, par quelque acteur que ce soit, ne peut se faire sans l'accord préalable du SRP et sans en mentionner la source.

ÉLÉMENTS D'INTERPRÉTATION ET DE COMPRÉHENSION

- **Remarque préliminaire :** les comparaisons des impacts d'un kg de MPR avec un kg de résine vierge données ci-dessous le sont à titre d'information et ne préjugent pas du taux réel de substitution retenu par l'utilisateur de la MPR.
- Sur les deux paramètres majeurs que sont le **"Réchauffement climatique"** et la consommation d'**"Énergie non renouvelable"**, la MPR PEHD Granulés est avantageuse par rapport à la résine PEHD vierge :

4 fois moins d'émission de CO_2 eq
3 fois moins d'énergie non renouvelable nécessaire pour sa production

- Dans l'optique d'un développement de l'économie circulaire et d'une volonté d'encourager une industrie bas carbone, cette étude montre que l'utilisation de MPR PEHD Granulés en substitution de PEHD vierge est à recommander à tous ceux qui souhaitent éviter des émissions de CO_2 et limiter la consommation d'énergie non renouvelable.



srp

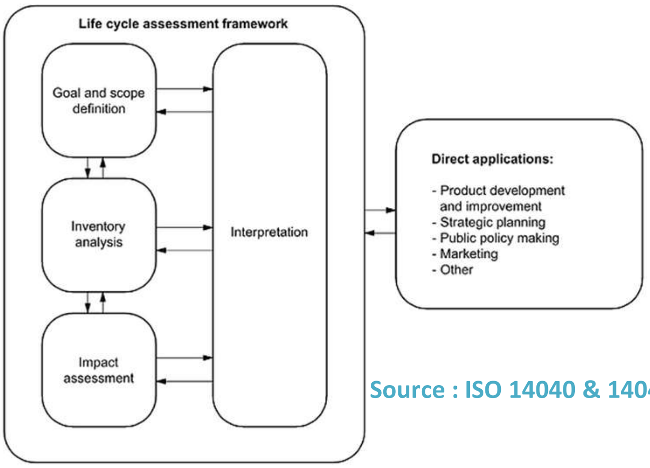
ECO-PROFIL d'1 kg de R-PEHD Granulés

- L'Eco-profil synthétise l'évaluation environnementale d'1 kg de R-PEHD Granulés qui comprend la collecte des déchets, leur tri, leur transport et toutes les opérations spécifiques de la régénération des déchets plastiques (lavage, broyage, densification, micronisation, granulation, compoundage) nécessaires à sa production.
- Toutes les données quantitatives de l'Eco-profil sont relatives à **1 kg de R-PEHD Granulés**, prêt à l'emploi, emballé et chargé, départ usine.
- L'Eco-profil est constitué d'un certain nombre de paramètres courants dans ce type d'étude. Ils sont chiffrés et répartis en quatre catégories :
  - Impacts environnementaux
  - Utilisation des ressources
  - Déchets éliminés
  - Flux sortants

IMPACTS ENVIRONNEMENTAUX	
Réchauffement climatique	**0,453 kg CO2 eq**
Appauvrissement de la couche d'ozone	9,82 E-08 kg CFC 11 eq
Acidification des sols et de l'eau	1,79 E-03 kg SO2 eq
Potentiel d'eutrophisation	5,04 E-04 kg(PO4)3- eq
Formation d'ozone photochimique	8,65 E-05 kg Ethylène eq
Épuisement des ressources abiotiques (éléments)	9,21 E-07 kg Sb eq
Épuisement des ressources abiotiques (fossiles)	49,7 MJ
Pollution de l'eau	0,452 m³
Pollution de l'air	47,2 m³
UTILISATION DES RESSOURCES	
Énergie renouvelable procédé	2,23 MJ
Énergie renouvelable matière	0 MJ
Total énergie renouvelable	2,23 MJ
Énergie non renouvelable procédé	**13 MJ**
Énergie non renouvelable matière	43 MJ
Total énergie non renouvelable	56 MJ
Utilisation de matière secondaire	1,30 kg
Combustibles secondaires renouvelables	0 MJ
Combustibles secondaires non renouvelables	0 MJ
Utilisation nette d'eau douce	1,92 E-03 m³
DÉCHETS ÉLIMINÉS	
Déchets dangereux éliminés	3,62 E-03 kg
Déchets non dangereux éliminés	0,540 kg
Déchets radioactifs éliminés	1,24 E-04 kg
FLUX SORTANTS	
Matériaux destinés au recyclage	2,79 E-02 kg
Matériaux destinés à la récupération d'énergie	3,48 E-02 kg

How to make an LCA ?

LCA methodology



Source : ISO 14040 & 14044

How to make an LCA ?

1. Goal and scope definition

- Defining the objective behind making the LCA
- Defining the functionnal unit (FU) and the reference flow

The functional unit
« Quantified performance of a product system for use as a reference unit » (ISO 14040 :2006)

Example: Orange Juice Brick
FU = "Contain, protect, store 250 ml of orange juice during its lifetime“
RF = One 250ml capacity brick

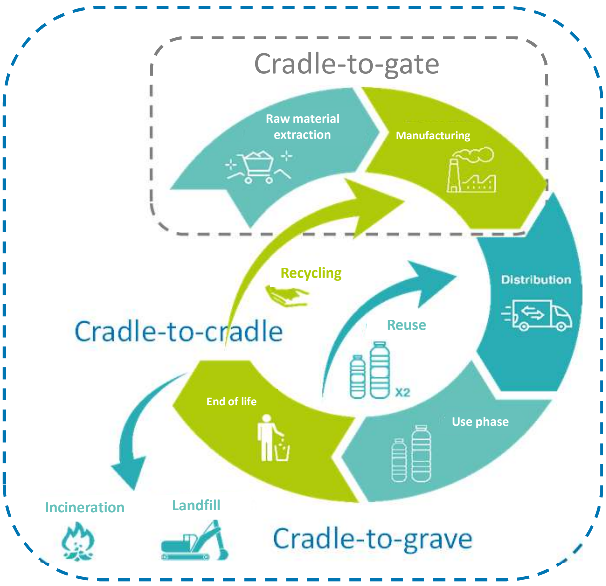
How to make an LCA ?

1. Goal and scope definition

- Defining system boundarie

System boundaries
« Set of criteria specifying which unit processes are part of a product system » (ISO 14044 :2006)

Gate-to-gate is a partial LCA looking at only one value-added process in the entire production chain.
Cradle-to-gate is an assessment of a partial product life cycle from resource extraction (cradle) to the factory gate (i.e., before it is transported to the consumer). The use phase of the product is omitted in this case. The disposal phase can be included depending on the objective of the analysis
Cradle-to-cradle is a specific kind of cradle-to-grave assessment (the full Life Cycle Assessment from resource extraction ('cradle') to use phase and disposal phase ('grave')), where the end-of-life disposal step for the product is a recycling process.



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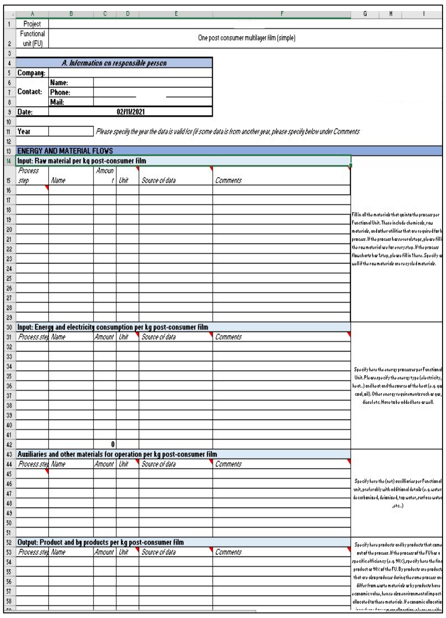
How to make an LCA ?

2. Inventory analysis

- Collecting life cycle data

Life cycle inventory
« The Life Cycle Inventory is the quantification of all the incoming and outgoing flows of a system. This is what makes it possible to carry out a Life Cycle Assessment » (ISO 14044 :2006)

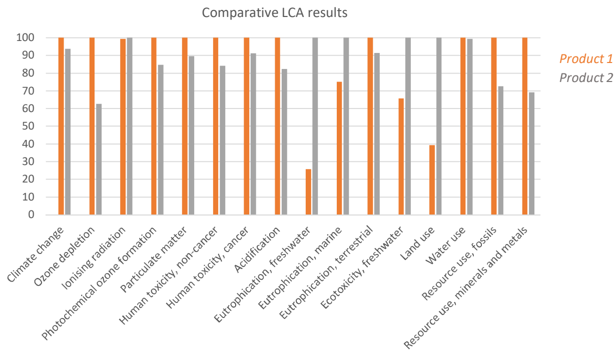


How to make an LCA ?

3&4. Impact evaluation and interpretation

« Translate the consumption and discharges identified during the inventoryinto environmental impacts » (ISO 14044 :2006)

- Analysis of the results
- Identification of significant issues
- Verification through completeness, sensitivity and consistency checking
- Explanation of the limitations of the previous steps (inventory and/or impact assessment)
- Provide recommendations in the most transparent way possible



LCA tools at IPC

SimaPro

- World leader LCA software
- Proposed for any type of application and for any field of activity
- Suitable for complex and simple LCA models
- Several databases including **Ecoinvent V3.9** , covering over 15,000 data
- Different methods of impact assessment, including the **PEF method (Product Environmetal footprint)** developed and recommended by the EU commission

C3R' IMPACT – L'ACV PAR IPC

- **Simplified LCA** software developed by IPC
- Intended for **Plastic and Composite industry**
- Uses Simapro as a background for calculation
- Includes data from Ecoinvent 3.9, specific data collected by IPC, and SRP (plastic recyclers union in France)
- Uses **PEF calculation method**

ANNEX VIII

Presentation of the biodegradation experiments carried out within IPC

Centre Technique Industriel
de la Plasturgie et des Composites, Bellignat

Centre Technique Industriel
de la Plasturgie et des Composites

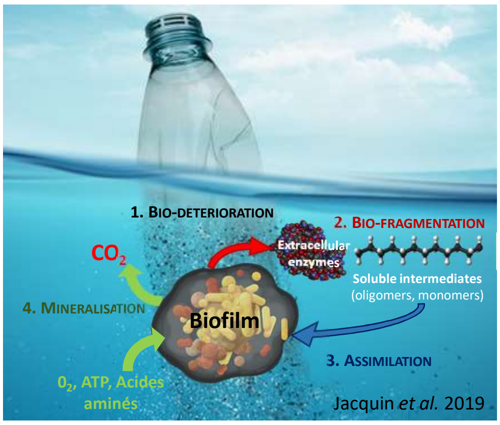
Faire aboutir ensemble
Vos projets d'innovation
Plastiques et Composites.

Technical teaching course

Presentation of the biodegradation experiments carried out within IPC

ct-ipc.com

Biodegradation of a plastic by the plastisphere



Conversion of organic carbon into biogas and biomass associated with microbial community activity

Study of biodegradation in industrial or domestic composting conditions

Stantards EN 13 432 and NF-T51800

- The standards require a complete study of biodegradation
  - Physico-chemical parameters of the material
  - Organic carbon mineralization
  - Study of polymer fragmentation
  - Impact on plant toxicity

Study of the biodegradation of materials in domestic/industrial compost

INDUSTRIAL

- **Temperature:** 58°C
- **Biodegradation (6 months max):**
  - Reference : 70% in 45 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration (3 months max):**
  - NF ISO 20 200 or ISO 16929
  - <10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 208
  - Between 14 and 21 days after germination of 50% of the control seedlings
  - Germination rate > 90% relative to control

HOME

- **Temperature:** 25°C
- **Biodegradation (12 months max):**
  - Reference : 70% in 90 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration (6 months max):**
  - NF ISO 20 200 or ISO 16929
  - <10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 208
  - Between 14 and 21 days after germination of 50% of the control seedlings
  - Germination rate > 90% relative to control

Study of the biodegradation of materials in domestic/industrial compost

OK compost INDUSTRIAL (TÜV AUSTRIA)

- **Temperature:** 58°C
- **Biodegradation (6 months max):**
  - Reference : 70% in 45 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration (3 months max):**
  - NF ISO 20 200 or ISO 16929
  - <10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 208
  - Between 14 and 21 days after germination of 50% of the control seedlings
  - Germination rate > 90% relative to control

OK compost HOME (TÜV AUSTRIA)

- **Temperature:** 25°C
- **Biodegradation (12 months max):**
  - Reference : 70% in 90 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration (6 months max):**
  - NF ISO 20 200 or ISO 16929
  - <10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 208
  - Between 14 and 21 days after germination of 50% of the control seedlings
  - Germination rate > 90% relative to control

Study of the disintegration of materials in domestic/industrial compost

OK compost INDUSTRIAL (TÜV AUSTRIA)

- **Temperature:** 58°C
- **Biodegradation (6 months max):**
  - Reference : 70% in 45 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration (3 months max):**
  - NF ISO 20 200 or ISO 16929
  - <10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 208
  - Between 14 and 21 days after germination of 50% of the control seedlings
  - Germination rate > 90% relative to control

OK compost HOME (TÜV AUSTRIA)

- **Temperature:** 25°C
- **Biodegradation (12 months max):**
  - Reference : 70% in 90 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration (6 months max):**
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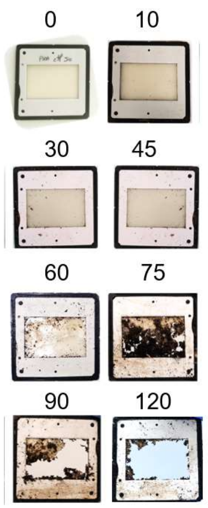


Study of the biodegradation of materials in domestic/industrial compost

OK compost INDUSTRIAL (TÜV AUSTRIA)

- **Study time:** < 6 months
- **Temperature: 58°C**
- **Biodegradation:**
  - Reference : 70% in 45 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration:**
  - NF ISO 20 200 or ISO 16929
  - <10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 208
  - Between 14 and 21 days after germination of 50% of the control seedlings
  - Germination rate > 90% relative to control

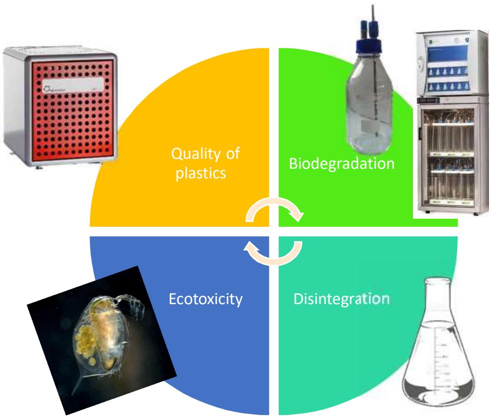
OK compost HOME (TÜV AUSTRIA)

- **Study time: < 12 months**
- **Temperature: 25°C**
- **Biodegradation:**
  - Reference : 70% in 90 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration:**
  - NF ISO 20 200 or ISO 16929
  - <10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 208
  - Between 14 and 21 days after germination of 50% of the control seedlings
  - Germination rate > 90% relative to control

Study of the biodegradation of materials in the marine environment

ASTM D 6691

- The standards require a complete study of biodegradation
  - Physico-chemical parameters of the material
  - Organic carbon mineralization
  - Study of polymer fragmentation
  - Impact on plant toxicity



Study of the biodegradation of materials in the marine environment

ASTM D 6691

- **Temperature: 30°C**
- **Biodegradation:**
  - Reference : 70% in 45 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration:**
  - Incubation according to ASTM D6691
  - Test over 84 days, < 10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 202
  - Study on the leachate obtained after 6 months of incubation at 30°C
  - No effect on daphnia magna

Study of the biodegradation of materials in the marine environment

- **Temperature: 30°C**
- **Disintegration:**
  - Incubation according to ASTM D6691
  - Test over 84 days, < 10% of DM after sieving at 2 mm

Study of the ecotoxicity of materials in the marine environment

- **Temperature:** 30°C
- **Biodegradation:**
  - Reference : 70% in 45 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration:**
  - Incubation according to ASTM D6691
  - Test over 84 days, < 10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 202
  - Study on the leachate obtained after 6 months of incubation at 30°C
  - No effect on daphnia magna

Study of biodegradation according to the type of medium

OK compost INDUSTRIAL

- **Biodegradation (6 months max):**
  - Reference : 70% in 45 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration (3 months max):**
  - NF ISO 20 200 or ISO 16929
  - <10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 208
  - Between 14 and 21 days after germination of 50% of the control seedlings
  - Germination rate > 90% relative to control

OK compost HOME

- **Biodegradation (12 months max):**
  - Reference : 70% in 90 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration (6 months max):**
  - NF ISO 20 200 or ISO 16929
  - <10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 208
  - Between 14 and 21 days after germination of 50% of the control seedlings
  - Germination rate > 90% relative to control 0

ASTM D 6691 — OK biodegradable MARINE

- **Temperature: 30°C**
- **Biodegradation:**
  - Reference : 70% in 45 days
  - Test: 90% absolute or relative to cellulose
- **Disintegration:**
  - Incubation according to ASTM D6691
  - Test over 84 days, < 10% of DM after sieving at 2 mm
- **Ecotoxicity**
  - OECD 202
  - Study on the leachate obtained after 6 months of incubation at 30°C
  - No effect on daphnia magna