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Sustainable and Green Electronics for Circular Economy

Deliverable 1.3

Validation and testing plan

Project Coordinator	Aly Syed, Philips Electronics Nederland B.V.		
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Authors' data

Author	Beneficiary	e-mail
Sirpa Nordman, Liisa Hakola	VTT: Sirpa.Nordman@vtt.fi, Liisa.Hakola@vtt.fi	
Luciano Rietter, Joel Antunes	PIEP: luciano.rietter@piep.pt, joel.antunes@piep.pt	
Final editor's address	Aly Syed Philips Electronics Nederland B.V. High Tech Campus 37 5656AE Eindhoven / Netherlands	

Management Summary

This document outlines the validation and testing plan of substrates, inks and adhesives developed and tested in SUSTRONICS project. The document details the development and testing plans for substrates, adhesives, inks, and other materials, specifying the properties to be measured and the testing methods.

Substrate testing will include properties testing such as surface roughness, tensile strength, and thermal resistance. Adhesive and ink testing will focus on properties like adhesion, curing conditions, and printability. Also, other materials are developed, such as sustainable LDS metallization solutions and carbon nanotubes.

Various partners are tasked with improving manufacturing processes, such as wire bonding on TPU and paper fluidics for diagnostic tools.

Since there are several partners developing and validating different material and process technologies, there will be some overlaps. Therefore, it is important to share the results among different partners to ensure joint learnings. Pilot meetings arranged in the frame of WP3 and status tracking process will be used to guarantee information transfer between the necessary partners. The final testing results will be presented in D1.6 at M24.

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1. Introduction

1.1. Purpose of the document

Testing and validation of materials and processes is an important phase during the development of new products and devices as they evince the fulfilment of the requirements and specifications set at the beginning of the project. Inside the task 1.4 Testing and validation of materials and processes, the definition of a plan to track the testing of several materials and different processes proposed for each application becomes necessary.

This document presents the current testing state of materials and processes proposed for all ten pilots of the project. More specifically, the focus is on analysing different material properties (surface properties, mechanical and chemical properties, processability properties among others) and processing properties (electrical performance achieved, process condition, material compatibility, yield, repeatability among others).

1.2. Structure of the document

This section consists of short-written description of the planned work of each partner with the tables containing the full description in an excel table respectively. Since this task and deliverable thereof consist of the work of several pilots and work packages tied together, the table format serves clearest way to present the vast work to be performed by the project partners.

The first section focuses on the material developments and its testing plan. The section is separated in different material areas:

- Bio-plastic substrates
- Cellulose based and other substrates
- Adhesives
- Inks
- Other Materials

For each material, the following information is presented:

- Measured Properties to be obtained;
- Testing/Measurement Method associated;
- Testing Owner – the responsible for the testing/validation.

The conclusions summarized the materials and processes to be developed and highlights their sustainability targets.

The tables in sections 2-3 include a comprehensive description of the development task, namely substrates, adhesives, inks, other materials and processes. Due to vast variety of substrates to be developed, they are divided into two separate sub-sections, namely bio-plastic substrates, and cellulose based and other substrates. There, the materials to be developed, their properties to be measured and the testing methods are listed. Also, the owners of the materials, as well as testing responsible and pilots with potential applications, are mentioned. An estimated time frame of each work is mentioned, this being flexible in some cases, due to interconnections between separate pilots.

1.3. Related documents

The definition of the testing plan for each material and process is directly linked to other deliverables previously submitted that support the construction of this document:

- D1.1 Materials Specifications and initial testing plan (M6)
- D1.2 Processes Specifications and initial testing plan (M6)

- D2.1 Requirements specification for component and devices (M6)
- D3.1 Initial system specification and design for pilots, including circularity aspects (M3)
- D3.2 Gen 1 prototypes, including characterisation and updates to system specification and design for Gen 2 (M15)

D3.1 has specified the initial material and process requirements transformed into target specification in D1.1 and D1.2. Furthermore, D2.1 contains component and device target specification, also transformed from D3.1. These components and devices will make use of materials and processes from WP1, thus interlinking with WP1. D3.2 has updated the target requirements of D3.1.

Furthermore, the following upcoming deliverable will report the results of the experiments listed in this document:

- D1.6 Material and process validation and testing results (M24)

2. Material Development

2.1. Substrates

Bio-based, renewable or otherwise sustainable substrates are provided by several partners.

2.1.1. Bio-plastic substrates

VTT provides new generation bio-based substrate materials based on bio-plastics and nanocellulose. ARNP also provides bio-plastic substrates based on PEF. Partners responsible of testing are mainly VTT, TNO, CEA and SCR. All evaluations are to be finished during 2024.

The substrate materials (Table 1) are PLA, bio-PET, chemically recycled PET, regenerated cellulose, bio-based PC, 100% bio-based polymer, bio-based polyester, bio-TPE, bio-TPU and PEF. Material properties such as surface roughness, opacity, contact angle with different solvents, tensile strength and thermal resistance will be measured from the substrate sheets.

Roll-to-roll(R2R) and/or sheet-to-sheet (S2S) printing tests will be performed with screen printing using test layout and silver, cobalt and/or carbon inks. Printability properties such as ink spreading, detail rendering, minimum gap width, minimum conductive line width, sheet resistance, volume resistivity, tape adhesion/cohesion, layer thickness and visual quality are monitored.

Table 1. *Bio-plastic substrates developed in SUSTRONICS project and their testing plan*

Materials to be developed	Owner	WP1 task	Pilots w/ Potential Application	How the materials are going to be tested?			Material testing starting
				Measured Properties	Testing/Measurement Method	Testing Responsible	
PLA Luminy L175	VTT	T1.2	P2.1, P2.2, P2.3 (P1.3)	**Material properties:** Surface roughness (Ra), opacity, contact angle with water and selected ink solvents, tensile strength (tensile strength, strain, Young's modulus), thermal resistance (Tg, melt entalphy, Tmelt, T crystall., Tdegradation start, coefficient of thermal expansion)	**Material properties (measured from substrate sheets):** - White-light interferometer (transparency Oulu) - DSC, TGA (thermal resistance) - Surface contact angle - Dilatometer test (thermal expansion) - AFM surface roughness - Biodegradation for PLA etc.	VTT / TNO / CEA / (Screentec?)	05/2024
				Printability: Ink spreading, detail rendering, minimum gap width, minimum conductive line width, sheet resistance, volume resistivity, tape adhesion/cohesion, layer thickness, visual quality	**Printability (R2R/S2S printing tests with screen printing using test layout and mainly silver and carbon inks):** - Optical microscope and SEM (spreading, detail rendering, minimum gap, visual quality) - Surface profilometer (thickness) - Digital multimeter + calculation from measured data or 4-point measurement (sheet resistance, volume resistivity) - Tape peeling + resistance measurement with multimeter before and after, or scratch test (tape adhesion/cohesion)	TNO / CEA / VTT / Screentec	
Bio-PET Eastlon CB602AB	VTT	T1.2	P2,1, P2.2, P2.3	**Material properties:** Surface roughness (Ra), opacity, contact angle with water and selected ink solvents, tensile strength (tensile strength, strain, Young's modulus), thermal resistance (Tg, melt entalphy, Tmelt, T crystall., Tdegradation start, coefficient of thermal expansion)	**Material properties (measured from substrate sheets):** - White-light interferometer (transparency Oulu) - DSC, TGA (thermal resistance) - Surface contact angle - Dilatometer test (thermal expansion) - AFM surface roughness	VTT / TNO	05/2024
				Printability: Ink spreading, detail rendering, minimum gap width, minimum conductive line width, sheet resistance, volume resistivity, tape adhesion/cohesion, layer thickness, visual quality	**Printability (R2R/S2S printing tests with screen printing using test layout and mainly silver and carbon inks):** - Optical microscope and SEM (spreading, detail rendering, minimum gap, visual quality) - Surface profilometer (thickness) - Digital multimeter + calculation from measured data, or 4-point measurement (sheet resistance, volume resistivity) - Tape peeling + resistance measurement with multimeter before and after, or scratch test (tape adhesion/cohesion)	TNO / CEA / VTT	

CumaPET 1704R (chemically recycled PET)	VTT	T1.2	P1.2, P2.2, P2.3	**Material properties:** Surface roughness (Ra), opacity, contact angle with water and selected ink solvents, tensile strength (tensile strength, strain, Young's modulus), thermal resistance (Tg, melt entalphy, Tmelt, T crystall., Tdegradation start, coefficient of thermal expansion)	**Material properties (measured from substrate sheets):** - White-light interferometer (transparency in Oulu) - DSC, TGA (thermal resistance) - Surface contact angle - Dilatometer test (thermal expansion) - AFM surface roughness	VTT / TNO	05/2024
				Printability: Ink spreading, detail rendering, minimum gap width, minimum conductive line width, sheet resistance, volume resistivity, tape adhesion/cohesion, layer thickness, visual quality	**Printability (R2R/S2S printing tests with screen printing using test layout and mainly silver and carbon inks):** - Optical microscope and SEM (spreading, detail rendering, minimum gap, visual quality) - Surface profilometer (thickness) - Digital multimeter + calculation from measured data, or 4-point measurement (sheet resistance, volume resistivity) - Tape peeling + resistance measurement with multimeter before and after, or scratch test (tape adhesion/cohesion)	TNO / CEA / VTT	
Regenerated cellulose Natureflex NP42	VTT	T1.2	P2.1, P2.2 (P3.1?)	**Material properties:** Surface roughness (Ra), opacity, contact angle with water and selected ink solvents, tensile strength (tensile strength, strain, Young's modulus), thermal resistance (Tg, melt entalphy, Tmelt, T crystall., Tdegradation start, coefficient of thermal expansion (CoE at TNO?)	**Material properties (measured from substrate sheets):** - White-light interferometer (transparency in Oulu) - DSC, TGA (thermal resistance) - Surface contact angle - Dilatometer test (thermal expansion) - AFM surface roughness - Biodegradation for PLA etc.	VTT / (TNO)	03/2024
				Printability: Ink spreading, detail rendering, minimum gap width, minimum conductive line width, sheet resistance, volume resistivity, tape adhesion/cohesion, layer thickness, visual quality	**Printability (R2R/S2S printing tests with screen printing using test layout and mainly Ag, Co and carbon inks):** - Optical microscope and SEM (spreading, detail rendering, minimum gap, visual quality) - Surface profilometer (thickness) - Digital multimeter + calculation from measured data, or 4-point measurement (sheet resistance, volume resistivity) - Tape peeling + resistance measurement with multimeter before and after, or scratch test (tape adhesion/cohesion)	VTT / Screentec	

Durabio D5380 (bio-based PC from MCC PTT)	VTT	T1.2	P2.3	**Material properties:** Surface roughness (Ra), opacity, contact angle with water and selected ink solvents, tensile strength (tensile strength, strain, Young's modulus), thermal resistance (Tg, melt entalphy, Tmelt, T crystall., Tdegradation start, coefficient of thermal expansion (CoE at TNO/CEA?)	**Material properties (measured from substrate sheets):** - White-light interferometer (transparency in Oulu) - DSC, TGA (thermal resistance) - Surface contact angle - Dilatometer test (thermal expansion) TNO/CEA? - AFM surface roughness	VTT / CEA (TNO?)	08/2024
				Printability: Ink spreading, detail rendering, minimum gap width, minimum conductive line width, sheet resistance, volume resistivity, tape adhesion/cohesion, layer thickness, visual quality, suitability for overmolding	**Printability (R2R/S2S printing tests with screen printing using test layout and mainly Ag, Co and carbon inks):** - Optical microscope and SEM (spreading, detail rendering, minimum gap, visual quality) - Surface profilometer (thickness) - Digital multimeter + calculation from measured data, or 4-point measurement (sheet resistance, volume resistivity) - Overmolding test	CEA / Forvia	
Brightplus Force (100% bio-based polymer)	VTT	T1.2	P2.1, P2.2 (P3.1?)	**Material properties:** Surface roughness (Ra), opacity, contact angle with water and selected ink solvents, tensile strength (tensile strength, strain, Young's modulus), thermal resistance (Tg, melt entalphy, Tmelt, T crystall., Tdegradation start)	**Material properties (measured from substrate sheets):** - White-light interferometer (transparency in Oulu) - DSC, TGA (thermal resistance) - Surface contact angle - Dilatometer test (thermal expansion) TNO? - AFM surface roughness - Biodegradation for PLA etc.	VTT	4/2024
				Printability: Ink spreading, detail rendering, minimum gap width, minimum conductive line width, sheet resistance, volume resistivity, tape adhesion/cohesion, layer thickness, visual quality, suitability for overmolding	**Printability (R2R/S2S printing tests with screen printing using test layout and mainly Ag, Co and carbon inks):** - Optical microscope and SEM (spreading, detail rendering, minimum gap, visual quality) - Surface profilometer (thickness) - Digital multimeter + calculation from measured data, or 4-point measurement (sheet resistance, volume resistivity) - Overmolding test	VTT	
EcoZen T95G (bio-based poyester from SK Chemicals)	VTT	T1.2	P1.2, P2.1, P2.2, P2.3	**Material properties:** Surface roughness (Ra), opacity, contact angle with water and selected ink solvents, tensile strength (tensile strength, strain, Young's modulus), thermal resistance (Tg, melt entalphy, Tmelt, T crystall., Tdegradation start), Coefficient of thermal expansion?	**Material properties (measured from substrate sheets):** - White-light interferometer (transparency in Oulu) - DSC, TGA (thermal resistance) - Surface contact angle - Dilatometer test (thermal expansion) TNO/CEA? - AFM surface roughness	VTT / (TNO)	08/2024
				Printability: Ink spreading, detail rendering, minimum gap width, minimum conductive line width, sheet resistance, volume resistivity, tape adhesion/cohesion, layer thickness, visual quality, suitability for overmolding	**Printability (R2R/S2S printing tests with screen printing using test layout and mainly Ag, Co and carbon inks):** - Optical microscope and SEM (spreading, detail rendering, minimum gap, visual quality) - Surface profilometer (thickness) - Digital multimeter + calculation from measured data, or 4-point measurement (sheet resistance, volume resistivity) - Overmolding test	VTT / TNO / CEA / (Screentec?)	

Bio-TPE **Bio-TPU**	VTT / TNO	T1.1	P3.3	**Material properties:** Surface roughness (Ra), tensile strength (tensile strength, strain, Young's modulus), shrinkage, water uptake	**Material properties (measured from manufactured substrate sheets):** - Stylus profiler (roughness) - Tensile tester - Oven (shrinkage) - Climatic chamber (water uptake)	TNO / VTT	6/2024
				Printability: Ink spreading, line definition, feature resolution, strain vs resistance, layer thickness, visual quality, cross-hatch adhesion, pencil hardness	**Printability (S2S printing tests with screen printing using test layout and a reference stretchable Ag ink):** - Optical microscope (spreading, line definition, feature resolution, visual quality) - Stylus profiler (thickness) - Elcometer (pencil hardness/cross-hatch adhesion) - Tensile tester with multimeter (strain vs. resistance)	TNO	6/2024
PEF (polyethylene furanoate)	ARNP	T1.2	P1.3	**Printability:** Ink spreading, line definition, feature resolution, layer thickness, visual quality, cross-hatch adhesion, pencil hardness	**Printability (S2S printing tests with screen printing using test layout and a reference Ag ink):** - Optical microscope (spreading, line definition, feature resolution, visual quality)	TNO	06/2024

2.1.2. Cellulose based and other substrates

Partners developing cellulose based and other substrates include TNO, UPM (also UPM together with VTT), TER, CAN, ARNP and PIEP. Substrate materials (Table 2) like carton boards, plywood, bio-PP based materials and papers among other materials are listed. In this section PIEP concentrates on LDS materials used in sensor modules, to discard PCB board in favour of 3DMID. PIEP will make a LCA score comparison between existing and developed solutions. VTT develops nanocellulose films.

Material properties are measured from manufactured substrate sheets. Properties such as surface roughness, tensile strength, shrinkage, thermal expansion and water uptake are measured.

Sheet-to-sheet (S2S) printing tests will be performed with screen printing using test layout and reference silver ink. Printability properties such as ink spreading, detail rendering, minimum gap width, minimum conductive line width, sheet resistance, volume resistivity, tape adhesion/cohesion, layer thickness and visual quality are monitored.

Table 2. *Cellulose based and other substrates developed in SUSTRONICS project and their testing plan*

Materials to be developed	Owner	WP1 task	Pilots w/ Potential Application	How the materials are going to be tested? Measured Properties	Testing/Measurement Method	Testing Responsible	Material testing starting
Carton boards (from Kotkamills and Pankaboard Plywood (from Koskisen)	TNO	T1.2	P1.2 P1.3	**Material properties:** Surface roughness (Ra), tensile strength (tensile strength, strain, Young's modulus), shrinkage, water uptake	**Material properties (measured from manufactured substrate sheets):** - Stylus profiler (roughness) - Oven (shrinkage) - Climatic chamber (water uptake)	TNO	03/2024
				Printability: Ink spreading, line definition, feature resolution, layer thickness, visual quality, cross-hatch adhesion, pencil hardness	**Printability (S2S printing tests with screen printing using test layout and a reference Ag ink):** - Elcometer (pencil hardness/cross-hatch adhesion) - Optical microscope (spreading, line definition, feature resolution, visual quality) - Stylus profiler (thickness)	TNO	03/2024
Renewable content PP film (Forest PP)	UPM	T1.2	P2.2	**Material properties:** Surface roughness (Ra), tensile strength, shrinkage	**Material properties (measured from manufactured substrate sheets):** - Tensile tester - Oven (shrinkage)	UPM	05/2024
				Printability: Ink spreading, line definition, feature resolution, strain vs resistance, layer thickness, visual quality	**Printability S2S (printing tests with screen printing using test layout and a reference EMS Ag paste:** - Substrate behaviour on sheet printing process: runnability (Screentec) - Thickness - Resistance - Edge quality - Adhesion - Dimentional stability	SCR, VTT, TNO	06/2024
PCR PET	UPM	T1.2	P2.2	**Material properties:** Surface roughness (Ra), tensile strength, shrinkage	**Material properties (measured from manufactured substrate sheets):** - Tensile tester - Oven (shrinkage)	UPM	06/2024
				Printability: Ink spreading, line definition, feature resolution, strain vs resistance, layer thickness, visual quality,	**Printability (S2S printing tests with screen printing using test layout and a reference EMS Ag paste):** - Substrate behaviour on sheet printing process: runnability (Screentec) - Thickness - Resistance - Edge quality - Adhesion - Dimentional stability	SCR, VTT, TNO	06/2024

UPM Formi 3D20/19 filaments (PLA base)	UPM/VTT	T1.2	P1.3	**Material properties:** Cofficient of thermal expansion, HDT 0,45MPa, Elongation at break, Modulus	- TMA - ASTM D 648/ ISO 75 - Tensile test	TNO/VTT/UPM/SIG	06/2024
UPM Formi EcoAce SPB 30 (Bio-PP base)	UPM/VTT	T1.2	P1.3	**Material properties:** Cofficient of thermal expansion, HDT 0,45MPa, Elongation at break, Modulus	- TMA - ASTM D 648/ ISO 75 - Tensile test	UPM/VTT/SIG	06/2024
UPM Formi EcoAce SPB 40 (Bio-PP base)	UPM/VTT	T1.2	P1.3	**Material properties:** Cofficient of thermal expansion, HDT 0,45MPa, Elongation at break, Modulus	- TMA - ASTM D 648/ ISO 75 - Tensile test	UPM/VTT/SIG	06/2024
UPM Formi Pro HP40 (PP base)	UPM/VTT	T1.2	P1.3	**Material properties:** Cofficient of thermal expansion, HDT 0,45MPa, Elongation at break, Modulus	- TMA - ASTM D 648/ ISO 75 - Tensile test	UPM/VTT/SIG	06/2024
Possible experimental grades	UPM/VTT	T1.2	P1.3	**Material properties:** Cofficient of thermal expansion, HDT 0,45MPa, Elongation at break, Modulus	- TMA - ASTM D 648/ ISO 75 - Tensile test	UPM/VTT	06/2025
Paper: 10002906 Electrical Insulation paper High	TER	T1.2	P1.3, P2.2, P3.1	**Printability:** Ink spreading, line definition, feature resolution, layer thickness, visual quality, cross-hatch adhesion, pencil hardness	**Printability (S2S printing tests with screen printing using test layout and a reference Ag ink):** - Optical microscope (spreading, line definition, feature resolution, visual quality) - Stylus profiler (thickness) - Elcometer (pencil hardness/cross-hatch adhesion)	TNO	01/2024
Paper: 10002883 Electrical Insulation paper Low	TER	T1.2	P1.3, P2.2, P3.1	**Printability:** Ink spreading, line definition, feature resolution, layer thickness, visual quality, cross-hatch adhesion, pencil hardness	**Printability (S2S printing tests with screen printing using test layout and a reference Ag ink):** - Optical microscope (spreading, line definition, feature resolution, visual quality) - Stylus profiler (thickness) - Elcometer (pencil hardness/cross-hatch adhesion)	TNO	01/2024
Paper: 10004696 thinstar plus 60	TER	T1.2	P1.3, P2.2, P3.1	**Printability:** Ink spreading, line definition, feature resolution, layer thickness, visual quality, cross-hatch adhesion, pencil hardness	**Printability (S2S printing tests with screen printing using test layout and a reference Ag ink):** - Optical microscope (spreading, line definition, feature resolution, visual quality) - Stylus profiler (thickness) - Elcometer (pencil hardness/cross-hatch adhesion)	TNO	01/2024

Paper: 10002848 Tesorb 165	TER	T1.2	P2.2, P3.1	**Printability:** Ink spreading, line definition, feature resolution, layer thickness, visual quality, cross-hatch adhesion, pencil hardness	**Printability (S2S printing tests with screen printing using test layout and a reference Ag ink):** - Optical microscope (spreading, line definition, feature resolution, visual quality) - Stylus profiler (thickness) - Elcometer (pencil hardness/cross-hatch adhesion)	TNO	01/2024
Paper: 10003361 Tesorb 93	TER	T1.2	P2.2, P3.1	**Printability:** Ink spreading, line definition, feature resolution, layer thickness, visual quality, cross-hatch adhesion, pencil hardness	**Printability (S2S printing tests with screen printing using test layout and a reference Ag ink):** - Optical microscope (spreading, line definition, feature resolution, visual quality) - Stylus profiler (thickness) - Elcometer (pencil hardness/cross-hatch adhesion)	TNO	01/2024
Paper: 10002626 thinjet 60	TER	T1.2	P1.3, P2.2, P3.1	**Printability:** Ink spreading, line definition, feature resolution, layer thickness, visual quality, cross-hatch adhesion, pencil hardness	**Printability (S2S printing tests with screen printing using test layout and a reference Ag ink):** - Optical microscope (spreading, line definition, feature resolution, visual quality) - Stylus profiler (thickness) - Elcometer (pencil hardness/cross-hatch adhesion)	TNO	01/2024
Paper: 10004506 thinjet silk 60	TER	T1.2	P1.3, P2.2, P3.1	**Printability:** Ink spreading, line definition, feature resolution, layer thickness, visual quality, cross-hatch adhesion, pencil hardness	**Printability (S2S printing tests with screen printing using test layout and reference inks, e.g. Ag and carbon):** - Optical microscope (spreading, line definition, feature resolution, visual quality) - Stylus profiler (thickness) - Elcometer (pencil hardness/cross-hatch adhesion)	TNO	01/2024
Paper: 10005059 thinbarrier® eco H-WS 45gsm	TER	T1.2	P3.2	**Printability:** Ink spreading, line definition, feature resolution, layer thickness, visual quality, adhesion (cross-cut test), sheet resistance and resistivity (if applicable)	**Printability (S2S printing tests with screen printing using test layout and reference inks, e.g. Ag and carbon):** - Optical microscope (spreading, line definition, feature resolution, visual quality) - Profilometer (thickness) - Cross-cut test for adhesion (ISO 2409) - 4-point measurement for sheet resistance and resisitivity	RISE	01/2024

Paper: 10003899 thinbarrier eco M-2S-WS 30gsm	TER	T1.2	P3.2	**Printability:** Ink spreading, line definition, feature resolution, layer thickness, visual quality, adhesion (cross-cut test), sheet resistance and resistivity (if applicable)	**Printability (S2S printing tests with screen printing using test layout and reference inks, e.g. Ag and carbon):** - Optical microscope (spreading, line definition, feature resolution, visual quality) - Profilometer (thickness) - Cross-cut test for adhesion (ISO 2409) - 4-point measurement for sheet resistance and resisitivity	RISE	01/2024
Polymer (plastic): Polyethylene Theraptalate medical grade	CAN	T1.2	P3.1			CAN	01/2024
LDS substrates	PIEP		P2.1	Quality of metallisation	- Conductivity of traces - Overflow of metallisation (short circuits)	PIEP	01/2024 ->
Nanocellulose film	**VTT**	T1.2	P1.3, P2.2, P3.1	**Material properties**: Tensile strength (tensile strength, strain,	**Measurements (measured from manufactured films):** - Tensile tester (strength properties)	VTT	03/2024

2.2. Adhesives

Adhesive development is conducted by UPM and RISE (Table 3).

UPM is responsible for RPMD (biocompatible, acrylic pressure sensitive adhesive) and skin irritation adhesive. Properties such as adhesion, cohesion, accelerated ageing and ISO10993 skin irritation test are investigated. Skin testing methods used are FTM 2, 5 & 8.

RISE is responsible for non-conductive and conductive adhesives. Material properties like adhesive strength, curing conditions, mechanical properties, anisotropy of conductivity and conductivity are monitored. Testing methods include force testing for adhesive strength with different bonding surfaces/materials/devices, I-V measurements with different test structures for conductivity as well as rheometer and/or differential scanning calorimetry for curing tests and mechanical parameters.

Table 3. *Adhesives developed in SUSTRONICS project and their testing plan*

Materials to be developed	Owner	WP1 task	Pilots w/ Potential Application	How the materials are going to be tested?			Material testing starting	Comments / notes / issues
				Measured Properties	Testing/Measurement Method	Testing Responsible		
RPMD (biocompatible, acrylic pressure sensitive adhesive)	UPM	T1.1	P2.2 P3.2	- Adhesion - Accelerated ageing with selected face substrate - Cohesion - ISO10993 skin irritation test	FTM 2, 5 & 8	UPM	03/2024	12/2024 skin irritation test report
Skin irritation adhesive	UPM	T1.1	P2.2 P3.2	- Adhesion - Cohesion	FTM 2, 5 & 8	UPM	12/2024	ISO10993 tests to be started
Non-conductive and conductive adhesives	RISE	T1.2	P2.3 P3.2	- Adhesive strength - Curing conditions - Mechanical properties (e.g. glass transition temperature) - Anisotropy of conductivity - Conductivity	- Force testing for adhesive strength with different bonding surfaces/materials/devices - I-V measurements with different test structures for conductivity - Rheometer and/or differential scanning calorimetry (DSC) for curing tests and mechanical parameters	RISE	10/2024	

2.3. Inks

Ink development is conducted by RISE, UGOT/ESS, TAU and CAN (Table 4).

RISE is developing inks for a functional layer in temperature and humidity sensors. Ink properties like rheology, wetting characteristics, printability, adhesion on different substrates and ink stability are monitored. Measurements are made by rheometer and tensiometer and/or goniometer. Printability tests are made with screen printer by printing test patterns on various surfaces/substrates. Cross-cut tests are made for investigating adhesion properties. Also ink stability is investigated. First inks are already available but further improvement is needed.

UGOT/ESS is responsible for a metal oxide-based gel for enzyme sensor. Construction of gel and its response to the enzyme is investigated, as well as the effect of different parameters (such as enzyme concentration) on solution composition. Electrochemical impedance will be measured. The gels have already been constructed and tested for their electrochemical response. The response with enzyme concentration has also been tested. The effect of solution composition and interference from other substances is yet to be tested.

TAU will develop an electrode ink. Capacitance will be tested by CV-measurements.

CAN will develop a silver-chloride ink. Printability will be monitored. Line resistance after print will be tested by C-V measurements.

Table 4. *Inks developed in SUSTRONICS project and their testing plan*

Materials to be developed	Owner	WP1 task	Pilots w/ Potential Application	How the materials are going to be tested?			Material testing starting	Comments/ notes/ issues
				Measured Properties	Testing/Measurement Method	Testing Responsible		
Ink for functional layer in temperature sensors	RISE	T1.2	P3.2	- Rheological properties (e.g. viscosity) - Wetting characteristics (e.g. surface tension) - Printability - Adhesion (to different substrates) - Ink stability	- Rotational and oscillatory measurements with rheometer - Tensiometry and/or goniometry for surface tension - Printability tests by screen printing test patterns on various surfaces/substrates - Cross-cut tests for adhesion - Rheology, centrifugation, and accelated testing for ink stability assessment	RISE	09/2024	In coordination with process development in T1.3 and sensor development in T2.2
Ink for functional layer in humidity sensors	RISE	T1.2	P3.2	- Rheological properties (e.g. viscosity) - Wetting characteristics (e.g. surface tension) - Printability - Adhesion (to different substrates) - Ink stability	- Rotational and oscillatory measurements with rheometer - Tensiometry and/or goniometry for surface tension - Printability tests by screen printing test patterns on various surfaces/substrates - Cross-cut tests for adhesion - Rheology, centrifugation, and accelated testing for ink stability assessment	RISE	08/2024	In coordination with process development in T1.3 and sensor development in T2.2 First inks available, but further improvement needed
Metal oxide based gel for enzyme sensor	UGOT/ESS	T1.2	P3.2	- Construction of gels and its response to the enzyme - Effect of different parameters such as enzyme concentration solution composition	- Electrochemical Impedance	UGOT	04/2024	The gels have been constructed and tested for their electrochemical response. The response with enzyme concentration has been tested. The effect of solution composition and interference from other substances is to be tested
Electrode ink	TAU		P3.1; P3.2	- Capacitance	- CV-measurement	TAU		
Silver- Silver Chloride Ink	CAN		P3.1	- Printability - Line Resistance (after print)	- Printability tests - Automatic Test Equipment - CV-measurement	CAN	01/2024	

2.4. Other Materials

The Other materials than substrates, inks or adhesives are developed by PIEP, CAN and MEDUG (Table 5).

PIEP is responsible for more sustainable LDS metallization/chemical plating bath solutions. LCA comparison between existing and developed solution will be made.

CAN is developing carbon nanotubes. Properties to be investigated are transmittance measured by optical spectrometer and sheet resistance measured by four-point probe.

MEDUG is responsible for collecting urine samples from patient cohorts. The collected urine samples will be used for validating the developed electrochemical sensors from use case 3 (Pilot#3.1a). The samples were measured using the routine endocrine laboratory assay for urine biomarker testing.

Table 5. *Other materials developed in SUSTRONICS project and their testing plan*

Materials to be developed	Owner	WP1 task	Pilots w/ Potential Application	How the materials are going to be tested?			Material testing starting	Comments/ notes/ issues
				Measured Properties	Testing/Measurement Method	Testing Responsible		
More sustainable LDS metallization/chemical plating bath solutions	PIEP	T1.3	P2.1	LCA score	LCA comparison between existing and developed solution	PIEP/FHG	10/2024	Assistance from WP4 may be needed
Carbon nanotubes	CAN		P3.1	- Transmittance - Sheet resistance	- Optical Spectrometer - Four-Point Probe	CAN, URV, MEDUG, CSEM	06/2024	
Urine samples from patient cohorts	MEDUG	T1.4	P3.1a	The urine samples were measured using the routine endocrine laboratory assay for urine biomarker testing (e.g., urinary C-peptide and urinary creatinine)	The collected urine samples will be used for validating the developed electrochemical sensors from usecase 3 (pilot 3.1a). Note: to the partners who might need the urine samples	Fixed users: MEDUG, URV, CBmed. Potential users: CAN and CSEM	09/2024	Each partner involved will have access to urine samples with high, low, or normal C-peptide levels (10 mL specimen).

3. Manufacturing Process Development

Process development responsible are WUR, IZM, VTT, GUT, EDI, CEA/SYM, RISE, SCR and TAU (Table 6).

WUR and/or IZM is responsible for improving wire bonding on TPU, SMD bonding on TPU and adhesive bonding on TPU. The bonding properties will be tested by microsection and peel-off test.

VTT is responsible for improving paper fluidics for diagnostic tools by manufacturing and optimizing hydrophobic fluid guiding structures onto paper using different printing techniques. Sustainable materials such as PLA, natural waxes, beeswax etc. will be tested to form fluid guiding layers. TER will provide paper substrates. Optimization of printing parameters for flexography and/or screen printing will made. Visual evaluation of the channel quality and a water droplet flow in the channel will be made. Immunoassay on printed paper-based devices will be made.

VTT will also improve methodology for chip and high pitch SMD component bonding. Chip and SMD component bonding technology development on copper ink printed plastic/paper substrates will be performed by using novel experimental anisotropic conductive film materials and S-O-A commercially available dispensable ICA, ACA and NCA materials. The outcome will be evaluated by contact yield and MIL-883 bonding strength shear test when applicable.

GUT is responsible for characterization of 3D-printed dielectric materials by examination of dielectric and microstructural properties of 3D-printed materials on FDM and DLP printers. Several thermoelastic materials and ceramic-loaded photocurable resins provided by various suppliers, such as PLA, ABS, ASA, PETG, HIPS, TPU etc. and composites of these materials, as well as materials including ceramic particles like Al_2O_3, TiO_2 and Fe_2O_3, will be tested. The database of dielectric properties of 3D-printed materials is used to simulate dielectric overlays for the antenna which will be used in a base station. Measurements will be performed with a split post dielectric resonator (SPDR). Electrical conductivity of conductive materials is measured by direct current 4-wire method (DC4W). Microstructural characterization of composite materials is performed on a scanning Electron Microscope (SEM).

EDI is responsible for the methodology for manufacturing process of wearable systems, in which the core improvement will be based on the use and the configuration of interconnect fabric. This methodology aims at completely new wearables manufacturing process, so the actual process will not be fully implemented during the project and will instead be developed as a theoretical framework with limited proof-of-concept piloting instead. Thus, only the plausibility of implementation will be validated though practical implementation in pilot. The rest of the testing of this methodology will take place as computer simulation to prove the efficiency and sustainability of the interconnect approach.

CEA/SYM is responsible for the methodology for performing printing and thermoforming of foils as well as pick and place of SMDs for automotive pilot Pilot#2.3. GEN1 demo is fabricated using standard process parameters for printing and thermoforming of decor and functional foils. For the integration of new materials in GEN2, printing process will be optimised to obtain high quality print. Cross-cut tester will be used for evaluating the outcome, also shrinkage and conductivity will be measured.

RISE is responsible for the methodology for assembly of components on sustainable substrates, as well as finding methods for protecting the mounted components. The assembly methodology consists of flip-chip chip bonding of integrated circuits to printed conducting traces on flexible paper substrates. Properties such as contact resistance, contact yield, bonding strength and reliability and robustness issues are monitored. Contact resistance and contact yield will be evaluated by electrical measurements using custom test structures and/or real devices. Also bonding strength measurements, temperature cycling and climate chamber testing will be made.

RISE is also responsible for the process of screen-printing functional layers in temperature and humidity sensors and printing of conductive materials on flexible substrates. Test patterns printed on different substrates/surfaces will be evaluated by visual inspection, adhesion tests and by using profilometer as well as electrical measuring devices.

SCR is responsible for printing of copper and carbon inks onto different kinds of paper/bio-substrates. Properties like printability, material handling, functional performance and mechanical durability will be monitored. Some materials have already been tested.

TAU is responsible for the supercapacitor fabrication process. Properties such as capacitance and energy capacity are measured.

Table 6. *Processes developed in SUSTRONICS project and their testing plan*

Materials to be developed	Owner	WP1 task	Pilots w/ Potential Application	How the processes are going to be tested?			Material testing starting	Comments/ notes/ issues
				Tested/Developed Properties	Testing/Measurement Method	Testing Responsible		
Wire bonding on TPU	WUR	1.3	3.3, (3.2)	Adhesion	- Microsection - Peel-off test	WE		
SMD on TPU	WUR, FHG	1.3	3.3, (3.2)	Adhesion	- Microsection - Peel-off test	WE		
Adhesives on TPU	WUR, FHG	1.3	3.3, (3.2)	Adhesion	- Microsection - Peel-off test	WE		
Paper fluidics	VTT	1.3	3.1	**Manufacturing and optimization of hydrophobic fluid guiding structures onto paper using printing techniques:** - Used papers received from Tervakoski (Tesorb grade - chromatography-like paper) - if needed, substrate properties are to be optimized by Tervakoski (TER) - Different sustainable materials (PLA, natural waxes, beeswax etc.) are tested to form fluid guiding layers. PS (polystyrene) as reference material. - Optimization of printing parameters (number of layers, ink transfer volumes etc.) for flexography and/or screen printing"	- Visual evaluation of a water droplet flow in the channel (rate and extent) and the channel - Visual evaluation of the channel quality - Immunoassay on printed paper-based devices The initial analytical quality of the developed paper-based microfluidic devices by printing methods was assessed in an immunoassay corresponding to a conventional nitrocellulose-based assay platform. When the sample liquid with mouse antibody conjugated to gold is transported within the hydrophilic paper channel, binding on test line takes place with an anti-mouse antibody printed and immobilized by physical adsorption as an indication of a positive test result.	VTT	03/2024	Use of papers from TER (Tesorb grades - see interleaf "Substrate")
Methodology for chip and high pitch SMD component bonding	VTT	1.3	3.1, 3.2	Chip and SMD component bonding technology development on copper ink printed plastic/paper substrates using novel experimental anisotropic conductive film materials and S-O-A commercially available dispensable ICA, ACA and NCA materials.	- Contact yield - MIL-883 bonding strength shear test when applicable	VTT	When materials and applicable test substrates available	
Characterization of 3D printed dielectric materials	GUT	1.4	3.2, 3.3	**Examination of dielectric and microstructural properties of 3D printed materials on FDM and DLP printers:** - Several thermoelastic materials and ceramic-loaded photocurable resins are tested from various suppliers (i.e. Tethon, Anycubic, Spectrum, Zetamix, FEco, SiCeram, eSUN, Protopasta, Fiberology etc.) - Most common materials like PLA, ABS, ASA, PETG, HIPS, TPU ect. and composites of these materials, as well as materials including ceramic particles like Al_2O_3, TiO_2, Fe_2O_3 are tested - Printing parameters are optimized and materials are printed in the form of regular samples for dielectric and microstructural characterization - The database of dielectric properties of 3D-printed materials is used to simulate dielectric overlays for the antenna which will be used in a base station.	- Split post dielectric resonator (SPDR) is used for measurements of the complex permittivity of printed dielectric materials at 2.4GHz - Electrical conductivity of conductive materials is measured by direct current 4-Wire method (DC4W) - Microstructural characterization of composite materials is performed on a Scanning Electron Microscope (SEM)	GUT	Materials measured continously	

Methodology for manufacturing process of wearable systems	EDI	1.3	2.2	**The methodology will define a manufacturing process in which the core improvement will be based on the use and configuration of the interconnect fabric. As such, several properties will be evaluated for the interconnect fabric:** - The overall plausability of implementation of this process - The reachability of any randomly placed wearable node on the interconnect - The percentage of useful vs redundant interconnect lanes in any random wearable configuration - The average length and number of jumps in the interconnect between any two random wearable nodes - Efficiency of use of the interconnect material (e.g. copper)	Due to the fact, that this methodology aims at completely new wearables manufacturing process, the actual process will not be fully implemented during the project and will instead be developed as a theoretical framework with limited proof-of-concept piloting instead. Thus, only the plausability of implementation will be validated though practical implementation in pilot (creation of interconnect fabric, cutting and sewing the fabric into a wearable form, adding wearable sensor nodes and interconnecting the data flows). The rest of the testing of this methodology will take place as computer simulation in order to prove the efficiency and sustainability of the interconnect approach.	EDI	11/2024	
Methodology for performing printing and thermoforming of foils, and pick and place of SMDs for automotive pilot	CEA, SYM	1.3	2.3	GEN1 demo is fabricated using standard process parameters for printing and thermoforming of decor and functional foils. For the integration of new materials in GEN2, printing process will be optimised (thermal stabilisation, etc), so to obtain high quality print (alignment patterns).	- Cross-cut tester - Shrinkage - Conductivity	CEA/SYM	When materials available	
Methodology for assembly of components on sustainable substrates.	RISE	1.3	3.2, (2.3)	Methodology for flip-chip chip bonding of integrated circuits (ASIC dies) to printed conducting traces on flexible paper substrates. Methods for protecting mounted components. Properties: - Process parameters - Contact resistance - Contact yield - Bonding strength - Reliability and robustness	- Evaluation of contact resistance and contact yield by electrical measurements using custom test structures and/or real devices - Bonding strength measurements (force measurements) - Temperature cycling - Climate chamber testing	RISE	When materials available	Using non-conductive and conductive adhesive materials developed in T1.2
Printing of functional layers in sensors	RISE	1.3	3.2	Development of process for screen printing of functional layers in temperature and humidity sensors on flexible substrates including paper. Properties: - Design rules - Screen parameters - Printing parameters - Curing/annealing process parameters	- Printing of test patterns on different substrates/surfaces - Visual inspection - Profilometry - Electrical evaluation - Adhesion testing (in coordination with T1.2 and T2.2)	RISE		In coordination with ink development in T1.2 and sensor development in T2.2
Printing of conductive materials	RISE	1.3	3.2	Development of process for screen printing of conductive inks (e.g. copper) on flexible substrates including paper. Properties: - Design rules - Screen parameters - Printing parameters - Curing/annealing process parameters	- Printing of test patterns on different substrates/surfaces - Visual inspection - Profilometry - Electrical evaluation - Flexibility (bening radius) - Adhesion testing (cross-cut teseting)	RISE		In coordination with substrate testing

Printing of copper and carbon inks onto different kinds of paper/bio-substrates	SCR	1.3	1.3, 2.1, 2.2, 3.1, 3.3	- Printability - Material handling - Functional performance - Mechancial durability		VTT, TAU, MOV, SCR, EDI		Some already tested
Supercapacitor fabrication process	TAU	1.3	3.1, 3.3	- Capacitance - Energy capacity	CV-testing	TAU		

4. Conclusions

Vast variety of sustainable substrates, inks, adhesives and other materials are introduced, developed and tested in SUSTRONICS project. Also improving existing processes towards greener manufacturing is an important factor connected to material development, thus several sustainable processes are also developed and tested. Tables 7-9 summarise the different material and process technologies to be developed and validated in WP1 and their linkage to pilots (WP3) and sustainability claims to be further elaborated in WP4.

Table 7. *Sustainable substrates (T1.2)*

Technology	Owners	Sustainability claims						Pilots targeted									
		Bio-based	Renewable	Recycled	Sustainable sourcing[1]	EoL: Recyclable	EoL: Compostable	Pilot#1.1	Pilot#1.2	Pilot#1.3	Pilot#2.1	Pilot#2.2	Pilot#2.3	Pilot#3.1a	Pilot#3.1b	Pilot#3.2	Pilot#3.3
Bio-plastics	• VTT: commercial pellets/granules processed into films • ARNP: own commercial & experimental • UPM: own commercial & experimental	X		X	X	X	X[2]		X	X	X	X	X				X
Cellulose based (paper, cartonboard) & wood based	• TER: own commercial & experimental • TNO: commercial	X	X			X	X		X	X	X	X		X	X	X	
Nanocellulose film or foam	• VTT: own experimental	X	X			X	X			X		X		X	X		
Plastics	• UPM: own commercial & experimental • CAN: commercial • PIEP: LDS		X			X				X	X			X			

[1] e.g. side streams
[2] some grades

Table 8. *Sustainable inks, adhesives and other materials (T1.2)*

Technology	Owners	Sustainability claims								Pilots targeted									
		Bio-based	Renewable	Recycled	Abundant	Energy efficient processing	Safe solvents	EoL: Recyclable	EoL: Compostable	Pilot#1.1	Pilot#1.2	Pilot#1.3	Pilot#2.1	Pilot#2.2	Pilot#2.3	Pilot#3.1a	Pilot#3.1b	Pilot#3.2	Pilot#3.3
Pressure sensitive adhesives	• UPM: own commercial & experimental	X						X				X		X				X	
Non-conductive & conductive adhesives	• RISE: experimental • VTT: commercial	X				X		X				X		X	X	X		X	
Inks for sensor functional layers	• RISE: experimental for temperature and humidity • UGOT/ESS: experimental for enzymes	X					X	X										X	
Electrode ink	• TAU: experimental						X									X		X	
Conductive ink	• CAN: experimental				X			X								X			
LDS metallization	• PIEP: experimental				X	X		X					X						
Carbon nanotubes	• CAN: own commercial & experimental		X		X		X	X								X	X		

Table 9. *Sustainable processes (T1.2)*

Technology	Owners	Sustainability claims				Pilots targeted									
		Compatible with sustainable materials	Material efficient	Energy efficient	Working safety[1]	Pilot#1.1	Pilot#1.2	Pilot#1.3	Pilot#2.1	Pilot#2.2	Pilot#2.3	Pilot#3.1a	Pilot#3.1b	Pilot#3.2	Pilot#3.3
Printing	• RISE, SCR, TAU	X	X	X	X			X	X	X	X	X	X	X	X
3D printing	• GUT: dielectrics	X			X									X	X
Structural electronics	• CEA, SYM	X			X						X				
Component assembly	• WUR, FHG, CEA, SYM, VTT, RISE	X		X	X			X		X	X	X	X	X	X
Wire bonding	• WUR	X												X	X
Paper fluidics	• VTT	X	X	X	X							X	X		
Wearable systems	• EDI	X								X					

[1] e.g. no harmful solvents

Since there are several partners developing and validating different material and process technologies, there will be some overlaps. Therefore, it is important to share the results among different partners to ensure joint learnings. Pilot meetings arranged in the frame of WP3 and status tracking process as described in D1.1 will be used to guarantee information transfer between the necessary partners.

D1.6 (Material and process validation and testing results) at M24 will report the testing results for the planned experiments that are described in this document in sections 2-3. It will ensure that all planned tests are performed and/or justify if changes have been made. D1.6 will also be used as a tool to ensure that the results are aligned with component and device requirements from WP2 (described in D2.1), and with pilot requirements from WP3 (described in D3.1 and D3.2). Finally, consistency with material and process specifications as described in D1.1 and D1.2 will be reviewed.