

Silent Sensors

Making Tyres Intelligent

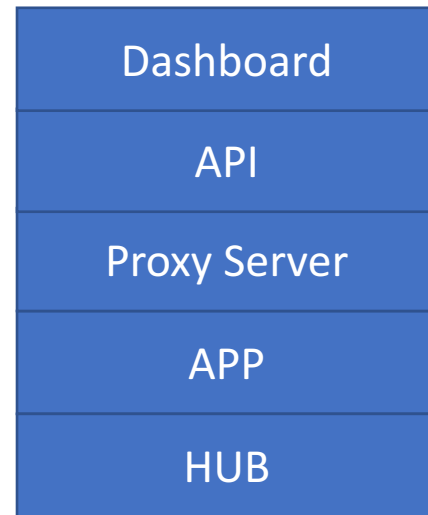
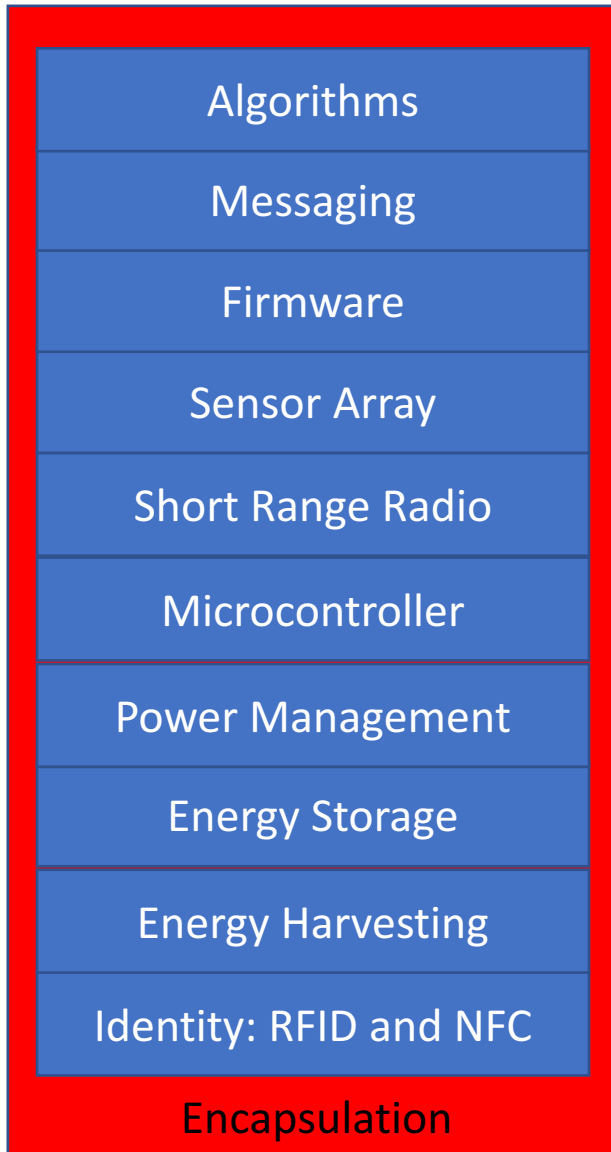
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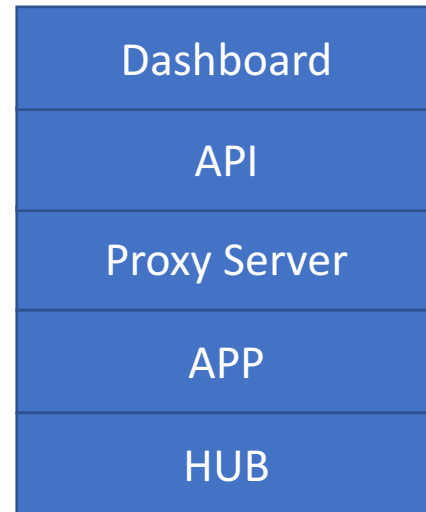
Aim for the Intelligent Tyre



- Silent Sensors **USP** is printed electronics and composites.
 - Ensures Lowest Cost
 - Highest flexibility for adding or printing components
 - Hybrid Approach
- Silent Sensors will deliver the **key components** to the industry over the next 2 years.
- **GoToMarket** with off the shelf components integrated into better form factors and systems.
- The **Intelligent Tyre is the goal** of many manufacturers including Bridgestone, Michelin, Pirelli, Goodyear and Continental.
- **Intelligent Tyres optimise** autonomous vehicles by providing the **finger tips** to the road.
- The intelligent **retreaded** tyres will make the autonomous vehicle much more climate friendly.
- Self powered **IOT sensors** expand the sensor array, sampling rate and reflexes of the tyre.
- **Algorithms** in the tyre will give **reflexes** to the car that up to now were the domain of the experienced driver.
- Tyre curing process means that the sensor package must survive 160 Celsius and 10mPA for 30 minutes.



Aim for the Intelligent Tyre



- Encapsulation – ARTIS, CPI NFC – Program of work funded by ERDF to identify range of materials
- RFID (UHF and NFC) – ARTIS, CPI and UoBath
- Piezo Energy Harvesting – CPI, UoBath funded by InnovateUK
- Vibration Energy Harvesting – Tyndall Institute
- Energy Storage and Triboelectric
- Power Management, Radio and TPMS Sensor
 - STE 433MHz
 - Sysgration BLE
 - SSL BLE NXP Pass Through
- Sensor Arrays - SSL
 - Six Axis motion
 - Autolocation
 - AutoConfiguration
 - Solid State Microphone
 - Atomic Mechanics
- Tread Depth Measurement
- Smart Inflator
- ULD Tracker

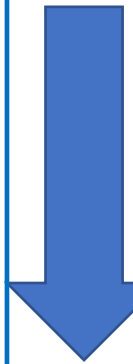


Silent Sensors is Making Tyres Intelligent

Tyre Manufacturer solutions to capture large-scale cost, safety & environmental efficiencies by Measuring, Monitoring and Managing a tyre's operating conditions over its lifetime to deliver measurable ROI.



Rapidly Growing Market Opportunities



Connected Autonomous Vehicles 25% of new vehicle market by 2035



ISO Standards, VDE requirements and Legislation for traceability and TPMS



2.8bn tyres on the road with continued, long term growth globally



Technology is transforming transport – Intelligent Tyre and CAV

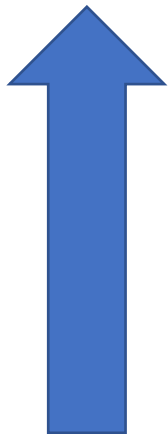


Suppliers are becoming service providers – pricing by km travelled



Reduce risk of accidents is public policy – 20% due to bad tyres

2016 Future of the Tire Industry by Smithers Rapra



100 million units by 2018 for major Tyre Mfgs



100 million units by 2018 for major Tyre Mfgs



BLE TPMS 400K units by 2019 major Tyre Mfgs



10% of ULDs units by 2019 – 150,000 units



Replacement OEM 100K units per annum



100K Energy Harvesting units by 2019



10m units by end of 2020 per annum



40K units by end of 2019 per annum

Silent Sensors Market Analysis based upon client input



Reducing Lifecycle Costs: Money, Risks & Environmental Impact

o Increased Safety

- Correct pressure reduces likelihood of accidents, breakdowns
- Track & Trace – its use history including operations, maintenance & retreads

o Lower Costs

- Lower Fuel Costs (3-5%)
- Premature Wear & Tear – last 10% of tyre life is most valuable

o Lessens Environmental Impact

- Lower CO2 emissions
- Longer tyre life, greater number of re-treads
- Reduced Landfill – more recycling options
- Lifecycle Management – Track & Trace

o Requirements for autonomous vehicle operations (Intelligent)

- Automation demands automatic measurement, monitoring & adjustment
- Big Data Applications

o Measure & Monitor

- Pressure
- Temperature
- Stress
- Alignment
- Tread Depth
- Fuel Security
- More....

Value-add ROI for today's Smart Tyres increasing with tomorrow's Intelligent Tyres



What is an Intelligent Tyre?

Intelligent Tyres *must be able to*:

- o **Uniquely Identify** Tyre throughout supply chain– including which vehicle and where
- o **Measure** pressure, temperature, alignment, tread depth
- o **Communicate** the measurements to the operator – driver, fleet, autonomous vehicle system, etc.
- o **Act on the information** to improve the vehicle’s performance – change pressure, replace tyre, etc.

Delivering Intelligent Tyres will have demanding Requirements:

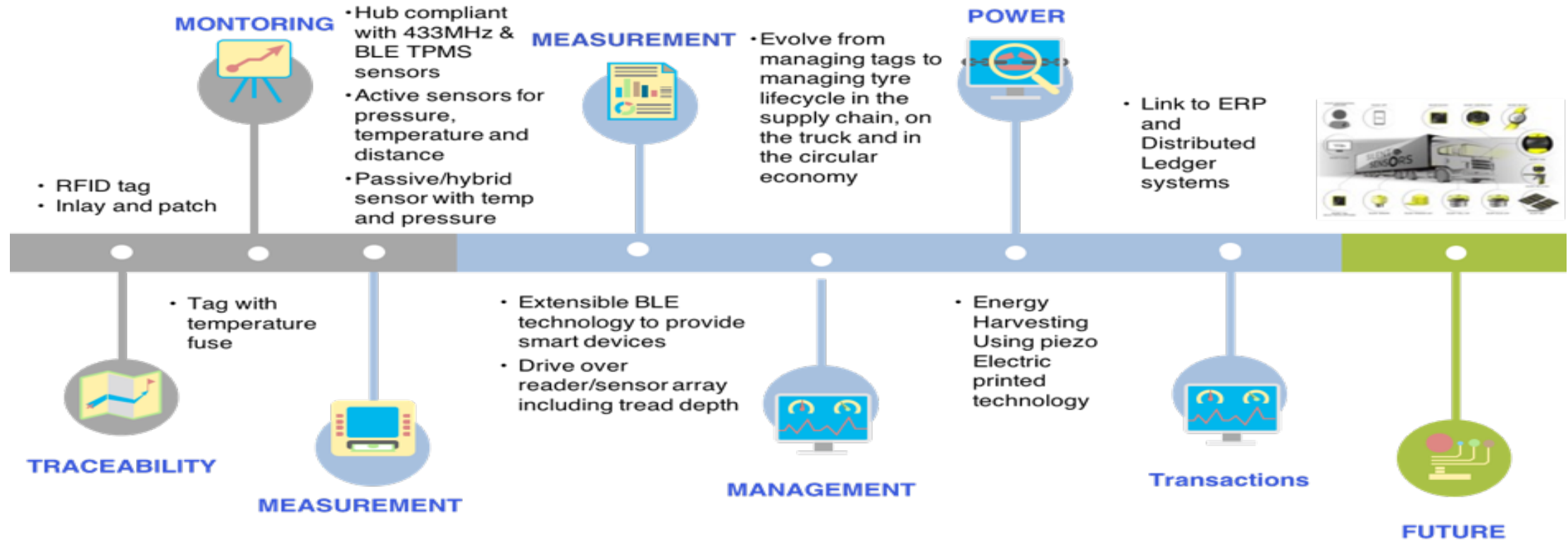
- o **Power** – Increasing power demands of sensors, communications and data requires power generation & storage
- o **Survive Super-heating** - 30 minutes at 160°C when sensors are embedded into tyres at point of manufacture
- o **Infrastructure** – Solutions require integration with 3rd party systems
- o **Time** – Investments will need to be made

Smart Tyres Components are Ready Now:

- o are ready now and able to deliver measurable ROI today
- o are the components of tomorrow’s Intelligent Tyre Solutions



Product Roadmap



2017-18 Go to Market with off the shelf TPMS and RFID

2018 Scale Up with SSL NFC/RFID Tags and BLE TPMS

2019 Smart inflator

2020 Self-powered Intelligent Tyre sensor

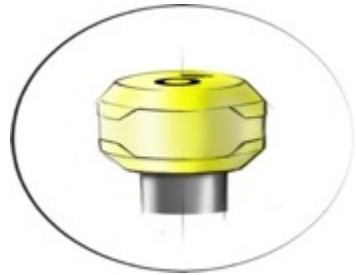
2021 Intelligent Tyre technology.

2021 Tyre Exchange



Market Ready Product & Solutions

3rd Party, Off-the-Shelf Products



o TPMS Sensors (BLE)



o RFID Tags

Proprietary Solutions

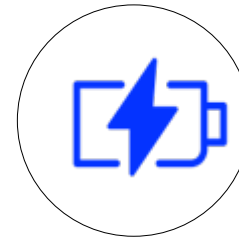


o Silent Hub

- Communicates w/ tags, sensors & 3rd party systems (FMS, ERP,)



o App, API and Cloud System



o Technology Expertise

- Consultancy
- System Integration
- 3rd party product development

- Combining printed electronics, composites, apps and the cloud into a complete tyre management solution for tracking and sensing throughout the tyre lifecycle
- Utilising NFC, Bluetooth, RFID, Composites, Apps and the Cloud enabling tyres to sense their environment for safer journeys, saving fuel and reducing pollution



Intellectual Property

o **Tyre Pressure Sensor with RFID**

- Tyre pressure Patent. Granted in USA, UK & pending in Canada, EU and China

o **Continuation Patent** (additional Parameters added to above)

- Added stress, strain, temperature and humidity. Granted in USA, UK & pending Canada, EU and China

o **Temperature Fuse**

- Thermoreactive ink printed in series with the antenna array and tamper tag. Patent applied UK

o **Trilobal Manufacturing Process**

- Novel Injection moulding to reduce the costs and produce light weight pass through sensor

o **Hot Tyre Inflation System**

- Temperature compensation between tyre and compressor

o **Trademark**

- “Silent” has been registered as a to help commercialise & protect innovation

o **Freedom to Operate**

- A recent prior-art patent search supports Silent Sensors’ ability to commercialise its technologies



Investment to Date

Strong track record of attracting funding grants - Over 1:3 with Equity

o **£900k Equity** – EIS Compatible

o **£2.2m Grants** & *More Pending*

- Current: InnovateUK (£350K), GateOne (£70K), EU H2020 (€50K) and ERDF (€200K)
- Completed: Climate KIC (€20k), H2020 Stage 1 (€50k)
- Granted: H2020 Stage 2 (€1.6m)
- Pending: Emflex £500K and InteliFlex £1.5m

o **Current Investment Round: £1.8m** – *EIS Qualifying*

- Covers 12 months operations with increased spend
- £7.8m pre-money valuation (£4.50/share)

o **Use of Proceeds**

- Transition Management Team to full time, Expand Team, Skills, Industry Experience – including Board
- Sales & Marketing, Capex
- Funding co-investment required for R&D grants
- Inventory of off the shelf components to drive short term revenues
- Capture existing Strategic Interest once current funding
- Prepare for 2018 Series A funding round – Institutional/VC Focus



Core Product 1 Requirement

- **New Material**
- **New Antenna**
- **Compatible with rubber**
- **Barrier Performance**
- **Right Mechanical**
- **Excellent adhesion**
- **New Silver Paste**
- **Pass Peel Test**
- **20% stretch**
- **Excellent Radio performance**
- Resonance
- Subtopic
- **New Encapsulation**
- **New assembly**
- **Ready for production**



Core Product 2 Requirement

- Established concept design in Product 1
- 2D patch
- Power requirements
- Same Substrates
- optimisation
- Energy Harvesting
 - PZT
 - Tribo
- Energy Storage
 - SuperCap
 - Battery
- Sensors
 - TPMS
 - Printed
 - Graphene
- Trilemma



Project Overview

- 2 Projects 70% Funded
 - H2020 Stage 2 Instrument – Ontrack
 - 2 Years
 - Start Date 16 October 2017
 - End Date
 - InnovateUK – Tyreless



Evolving Product Sets: Passive >> Smart >> Intelligent

Short Term Product Development	<ul style="list-style-type: none"> ○ Inlay TPMS RFID ○ Pass through Sensor ○ General Purpose Encapsulates - RFID/NFC, Smart Sensor ○ Smart Inflator
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	Launch Phase (2016-17) Passive Sensors	Revenue Growth (2018-19) Smart Sensors	Scaling Phase (2020-2022) Intelligent Tyres
Products & Services	<p>LF RFID</p> <p>TPMS</p>	<p>Traceability (UHF, NFC)</p> <p>Short Range Radio (BLE, microSP, 433MHz)</p> <p>Sensors & Microcontrollers</p> <p>Power (Energy Harvesting & Storage)</p> <p>Tyre Monitoring & Management</p>	<p>Fully integrated traceable tyre sensors with Energy Harvesting</p>
Integration & Enablers	<p>Subtractive Printed Electronics</p> <p>UHF Road Readers</p>	<p>Additive Printed Electronics</p> <p>Algorithms & Embedded Software</p> <p>Big Data, APIs, Apps & Analytics</p> <p>Infrastructure & Transactions</p>	<p>High Volume printed products with Cloud presence</p>

Medium Term Product Development
<p>Capabilities for Intelligent Tyres</p> <ul style="list-style-type: none"> ○ More capabilities will require more power <ul style="list-style-type: none"> ▪ Energy Harvesting & Storage Capabilities (in partnership with CPI, U of Bath, Tyndall, Bridgestone) ▪ Energy Storage (in partnership with Comberry) ○ New Components & Sensors <ul style="list-style-type: none"> ▪ Temperature, Stress, Alignment, Tread Depth, etc.



Project “OnTrack” – *Scaling up Manufacturing Readiness*

EU H2020 Stage 2 Instrument Grant

Pilot Plant to boost MRL – €2.2m total cost - grant contribution of €1.6m - **APPROVED**

- New substrate found that will enable us to get to market sooner UHMW PE
- New Silver based formulated and ready for use
- Boosting SSL’s Manufacturing Readiness Level (MRL)
 - **Stage 1 – Optimisation** Low Pilot Volumes (up to 20k units/day) to fully refine the production process;
 - **Stage 2 – Performance Verification** Pre-Production Pilot Volumes ($\leq 50k$ units/day) and
 - **Stage 3 – Commercialisation** Full Commercial Production ($\leq 160k$ units/day).
- CPI (Centre for Process Innovation) will provide expertise to assist in refining the production process to achieve our intended commercial volume manufacture. Although recent hires indicate that we will be able to do more inhouse sooner
- Spin out to own facility in vicinity of Sedgefield with manufacturing line.

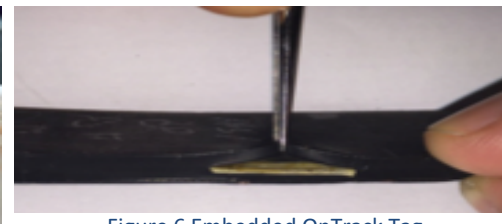


Figure 6 Embedded OnTrack Tag



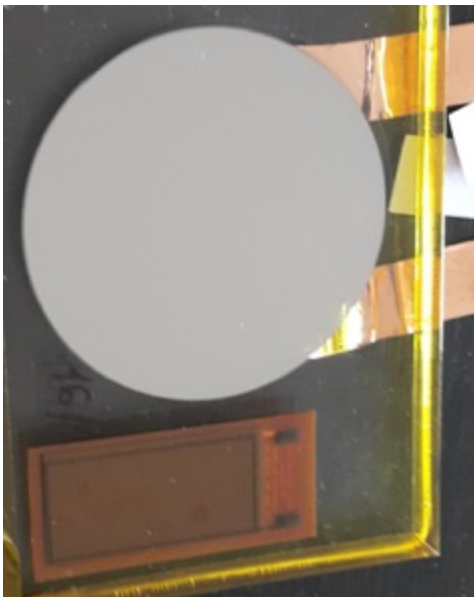
Figure 5 Bridgestone Tag Tests

Project "Tyreless" – Power Generator and Storage

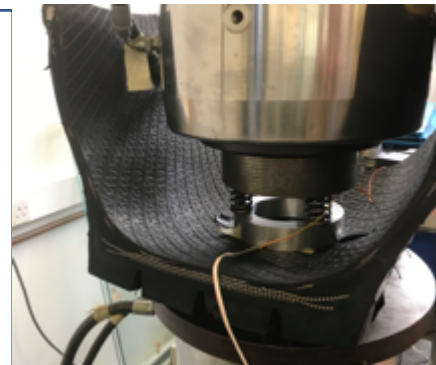
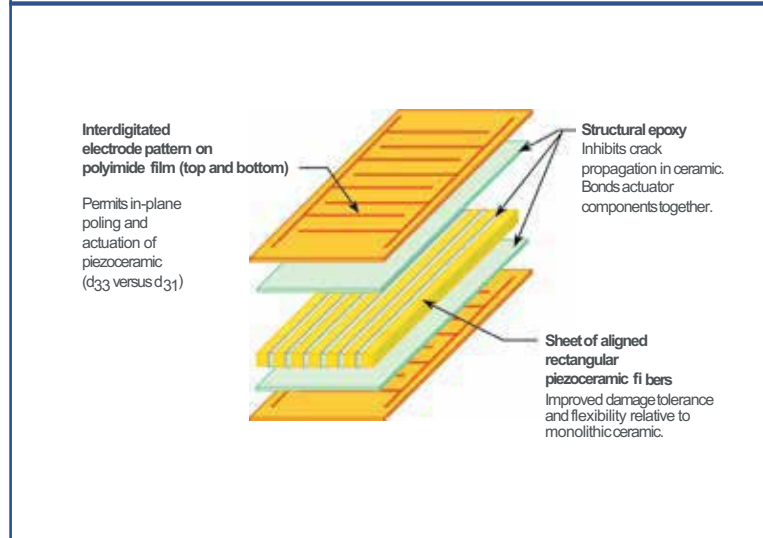
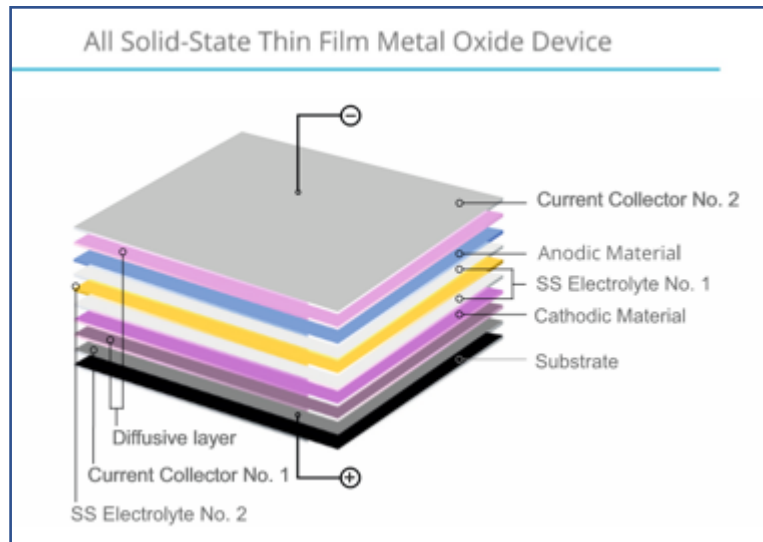
InnovateUK Grant – *Commenced*

The new RFID design will enable us to produce PZT piezoelectric materials on same PE substrate with same process.

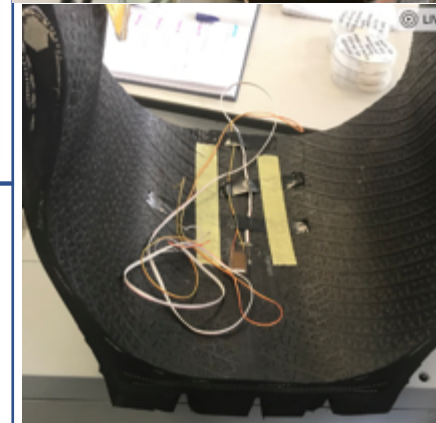
Thin Film Energy Storage material



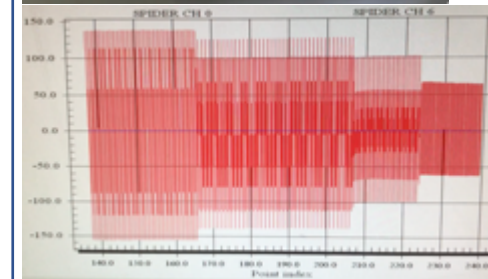
Tyreless Piezoelectric Harvesting material



Material being tested



Material attached to tyre



Graph showing output varying at different frequencies

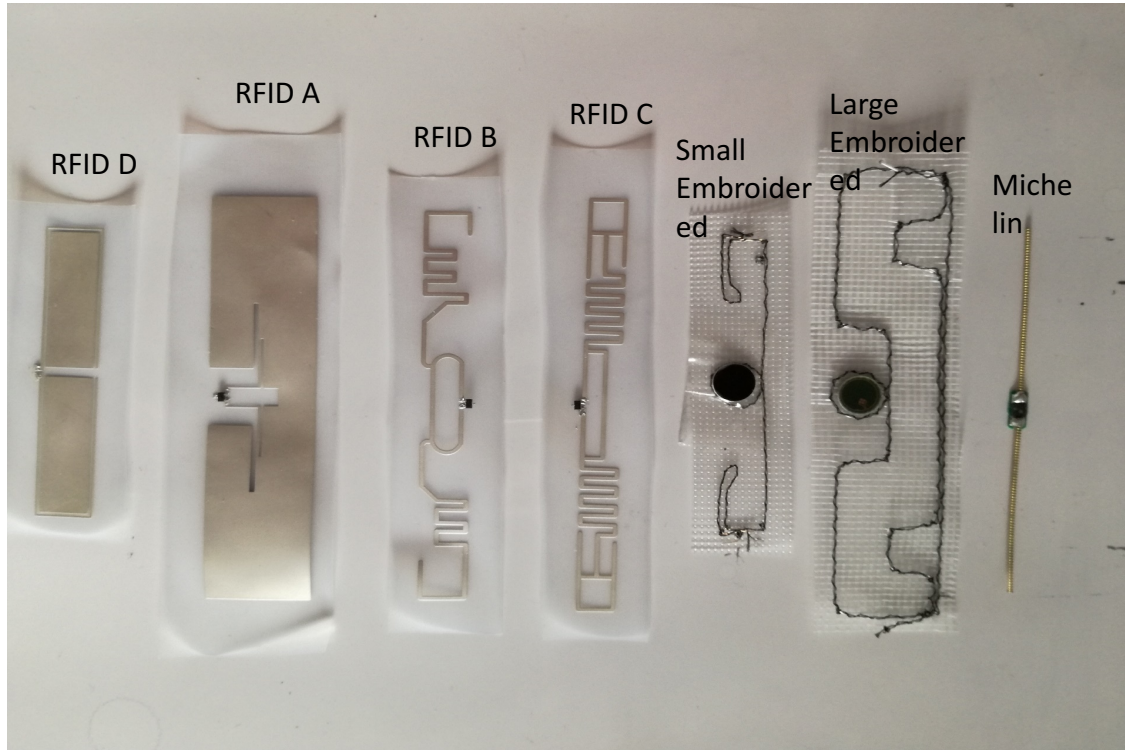


Project 1 – UHF and NFC tags

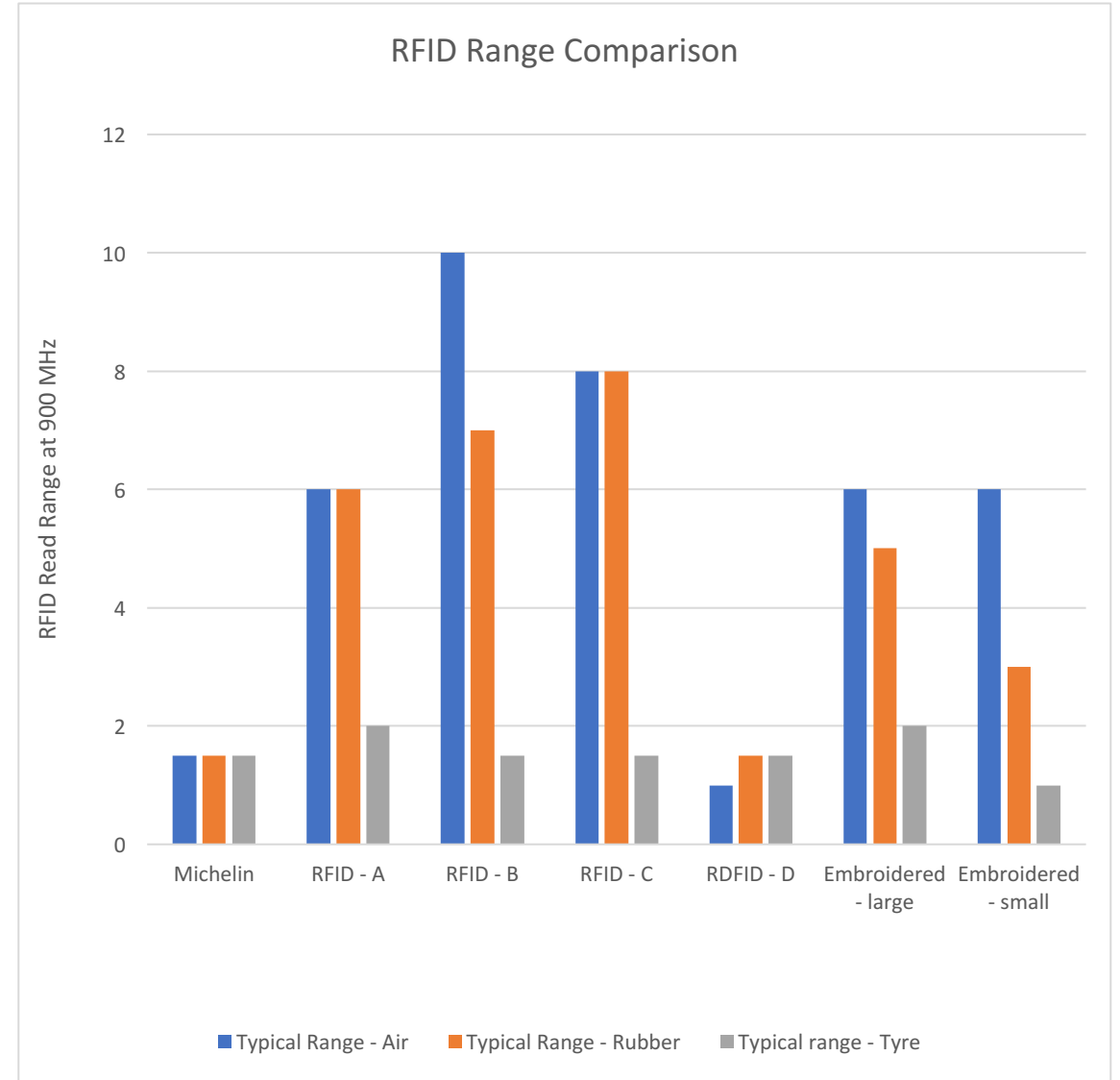
Status

- RFID/NFC Design for tyres
- Voyantic set up
- Paste developed for IC mounting
- Stretchable Ink
- Substrate tested and characterised
- Lab Scale process in place
- Manufacturing process under development

UHF Tag Range Initial Tests



3 Different types of tags were compared:
 UHMW PE, Embroidered and Curly Q



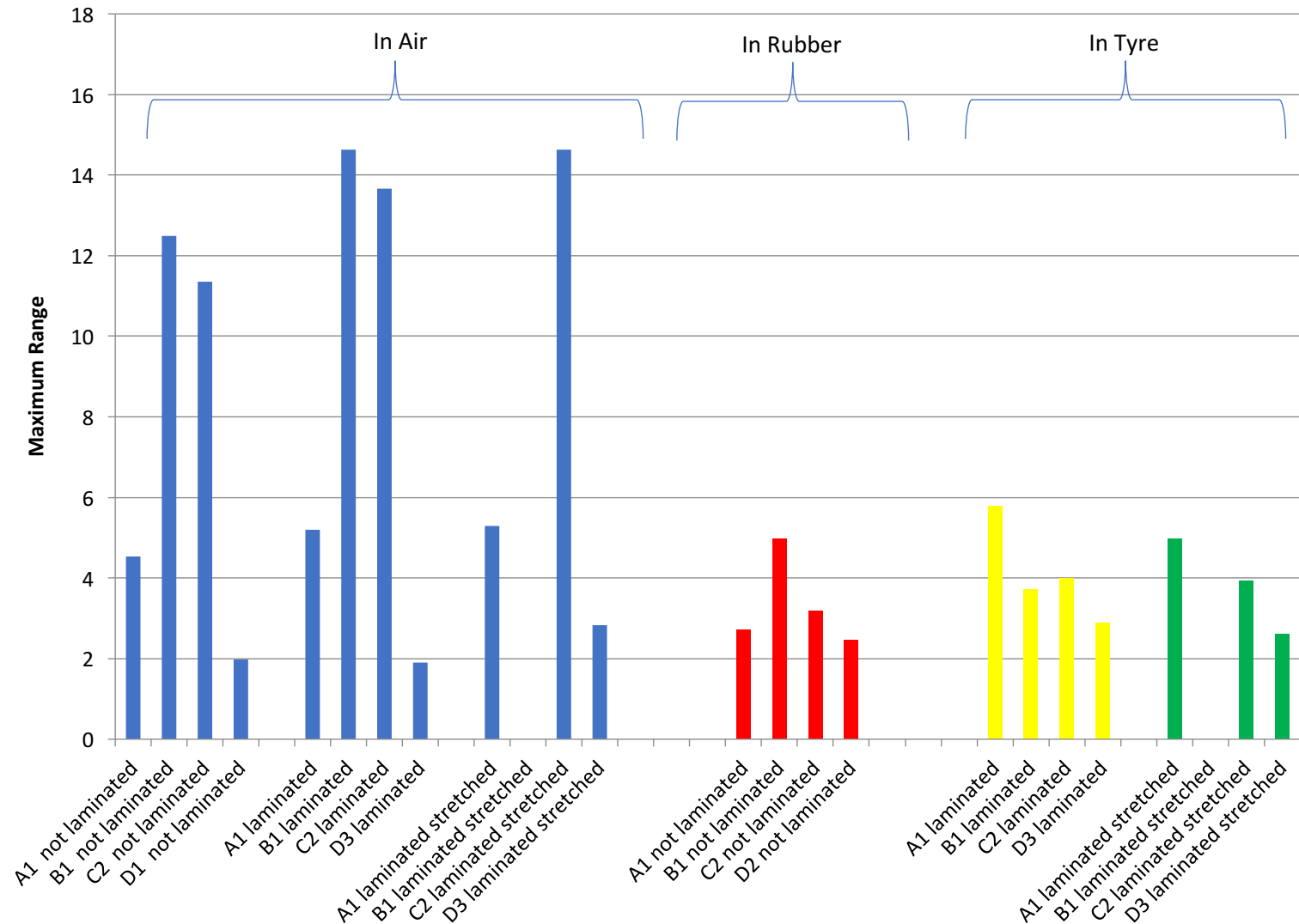
UHF Tag Range Performance – Inked Designs

In three environments:

- In Air
- In Rubber
- In Tyre

For three stages of processing:

- Not Laminated
- Post Lamination
- Post Stretching (20%)



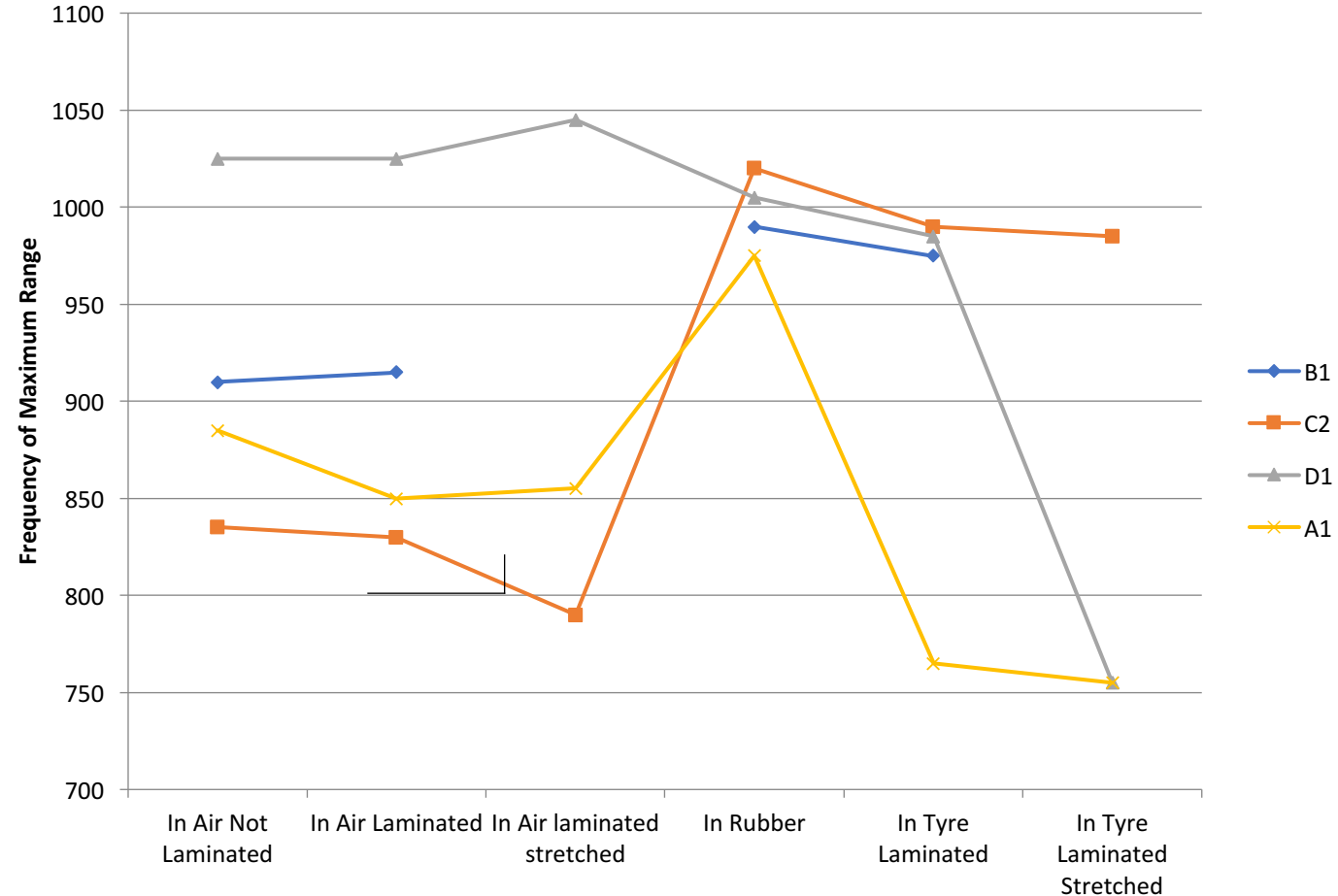
UHF Tag Frequency Effects

In three environments:

- In Air
- In Rubber
- In Tyre

For three stages of processing:

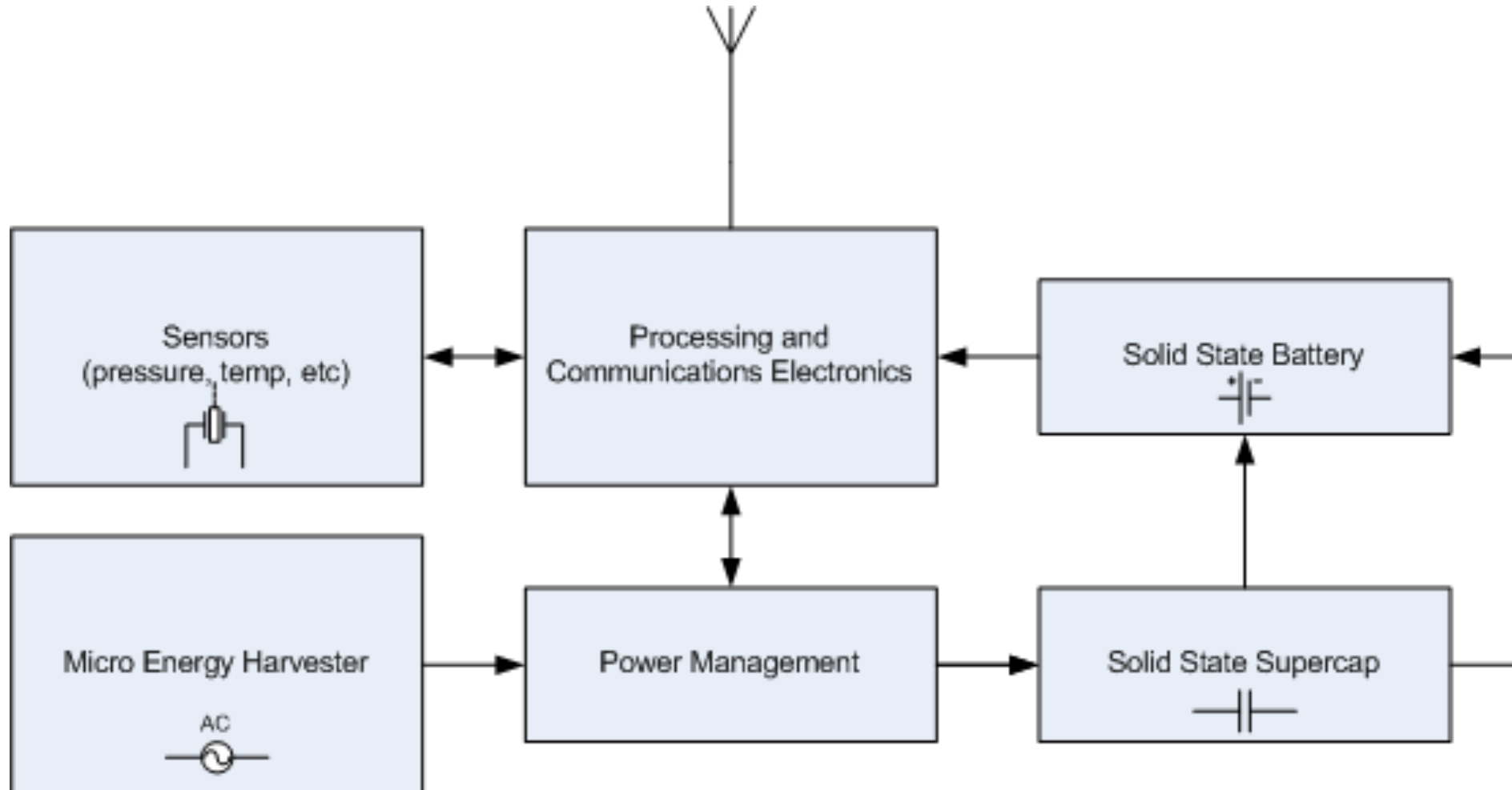
- Not Laminated
- Post Lamination
- Post Stretching (20%)



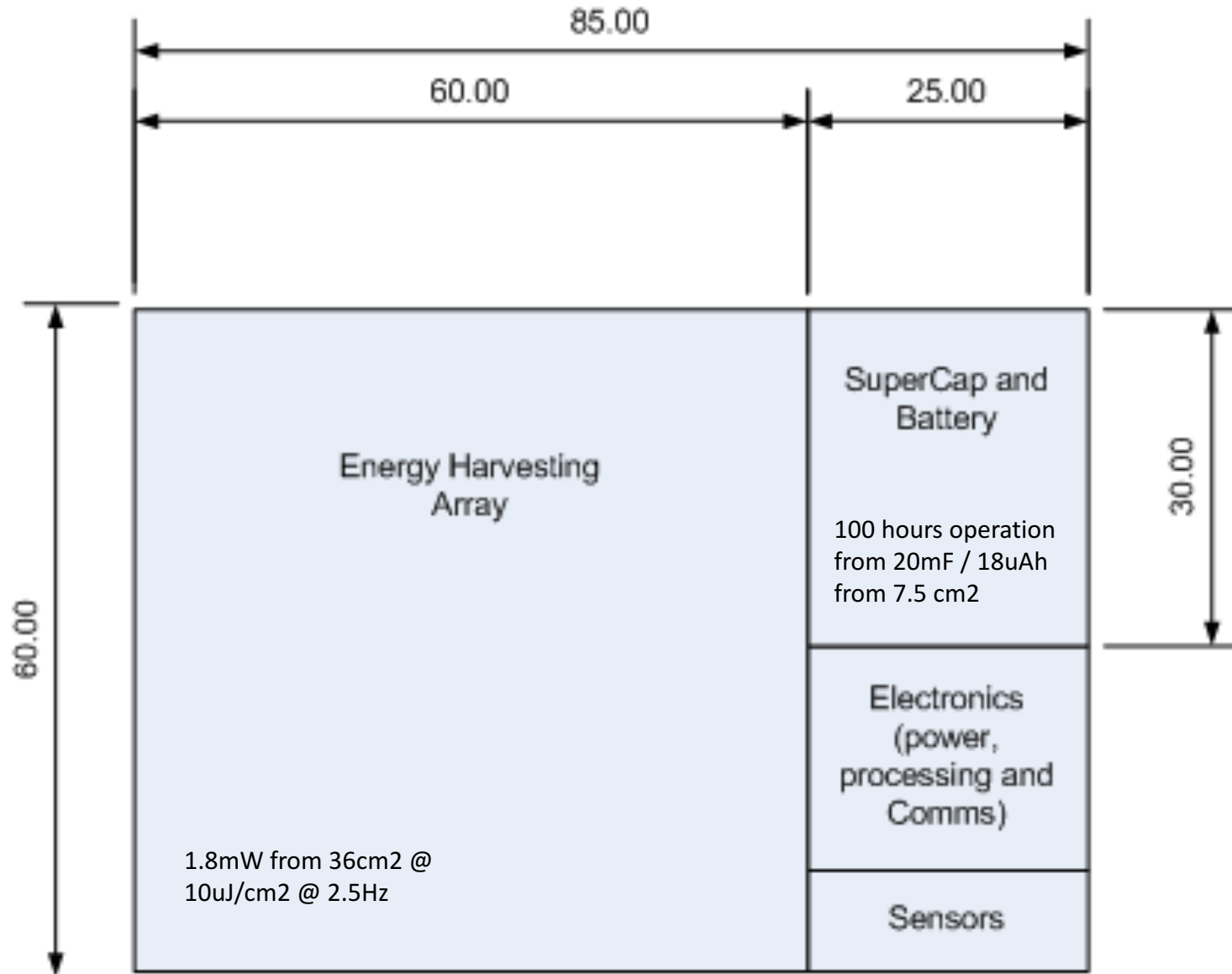
Project 2 – Energy Harvesting and Storage for 2D TPMS Sensors



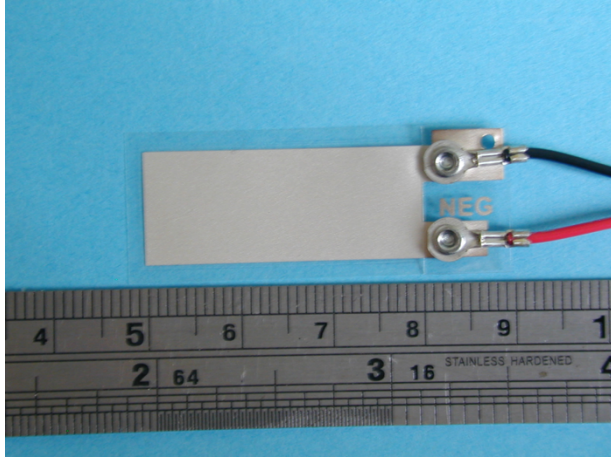
Intelligent Tyre Concept and Components



Intelligent Tyre Potential Component Footprint

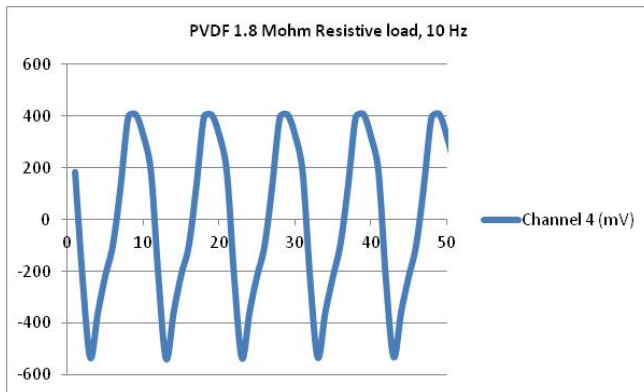


PVDF flexible Piezo-electric patch Tests



PVDF flexible piezo electric patch with electrodes

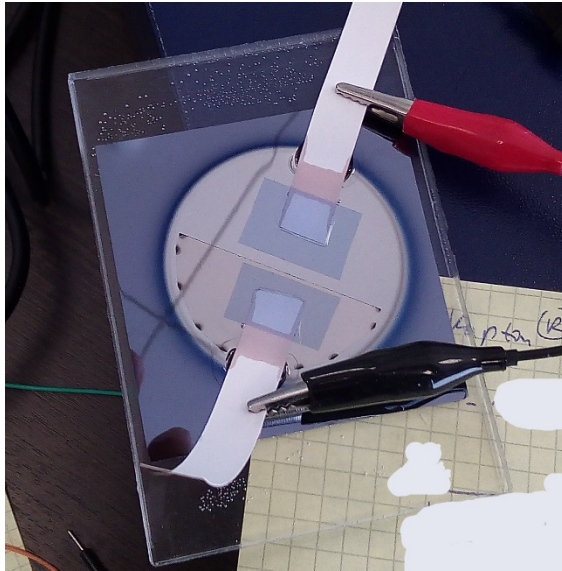
Vehicle Speed (mph)	15	30	60
Tyre Diameter (mm)	872.8	872.8	872.8
Flex Rate (Hz)	10Hz	5Hz	2.5Hz
Test Patch Output (Volts p-p)	0.4	0.3	0.125
Test Patch Output (Volts rms)	0.28	0.21	0.0875
Load (ohms)	1.80E+06	1.80E+06	1.80E+06
Power (mW)	4.36E-05	2.45E-05	4.25E-06



Typical Output Characteristics



MPU components for power storage



All-Solid State Battery

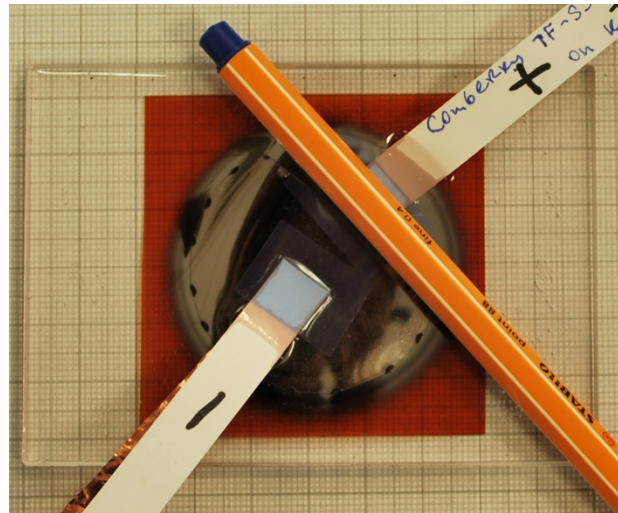
Voltage = 2.2...4.2 V

Capacity = 0.5...2.4 mAh

ESR = 50...120 Ohms

-50...+150 °C operating temp. range

-150...+200 °C shelf temp.



All-Solid State Pseudocapacitor

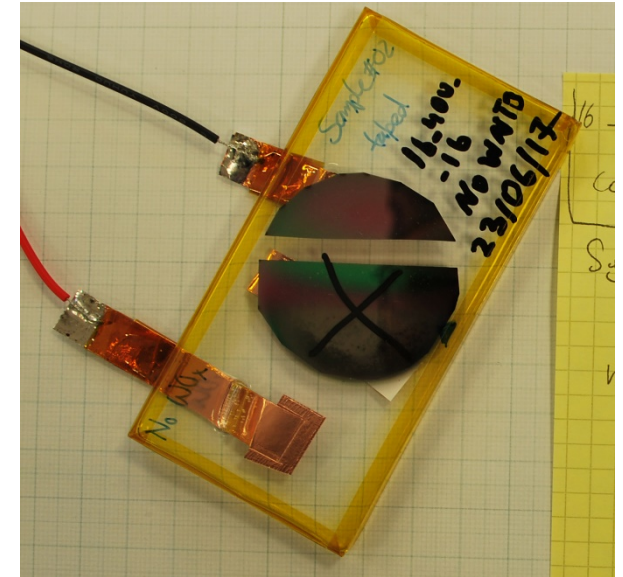
Voltage = 2.8...3.2 V

Capacity = 10...60 uAh

ESR = 1...10 Ohms

-50...+150 °C operating temp. range

-150...+200 °C shelf temp. range



All-Solid State Supercapacitor

Voltage = 4.5...5.0 V

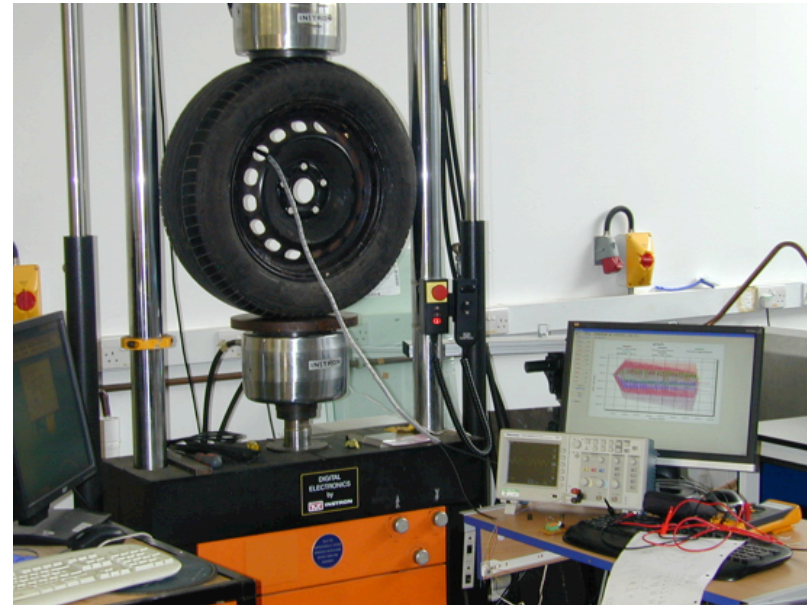
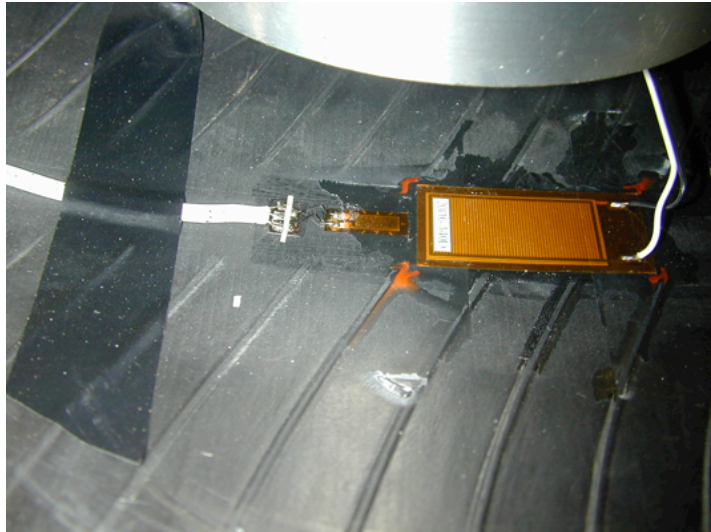
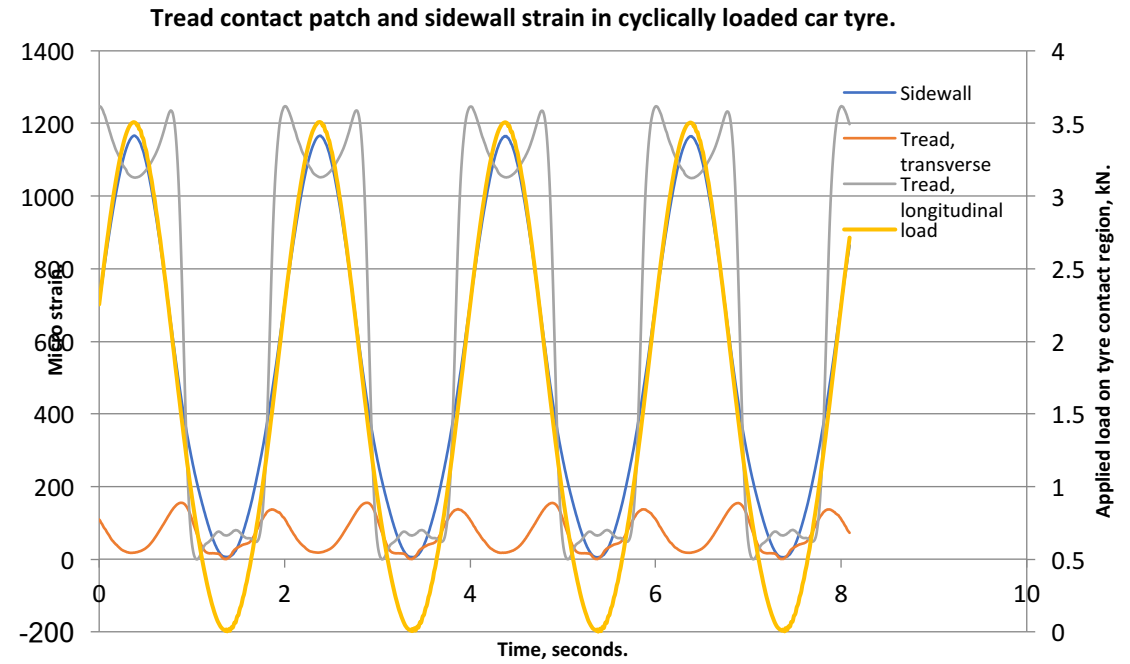
Capacity = 4-10 uAh

ESR = 0.04...0.06 Ohms

-50...+150 °C operating temp. range

-150...+200 °C shelf temp. range

Fully Instrumented testing



Power generating components for the MPU assembling

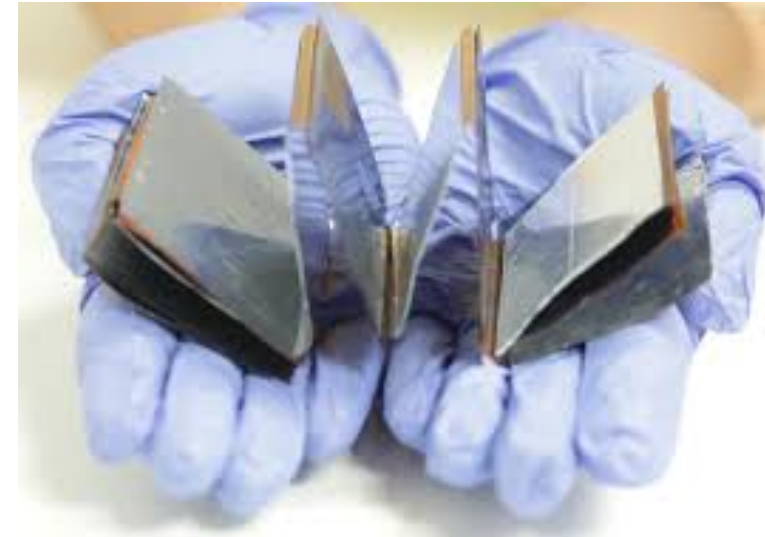


Piezoelectric Generator

Voltage = 5-10 V

Current = 0.05-1 mA

Power = 0.25...5 mW/cm²



Triboelectric generator

Voltage = up to 500 V

Current = 70-100 μ A

Power = 35...50 mW/cm²

28

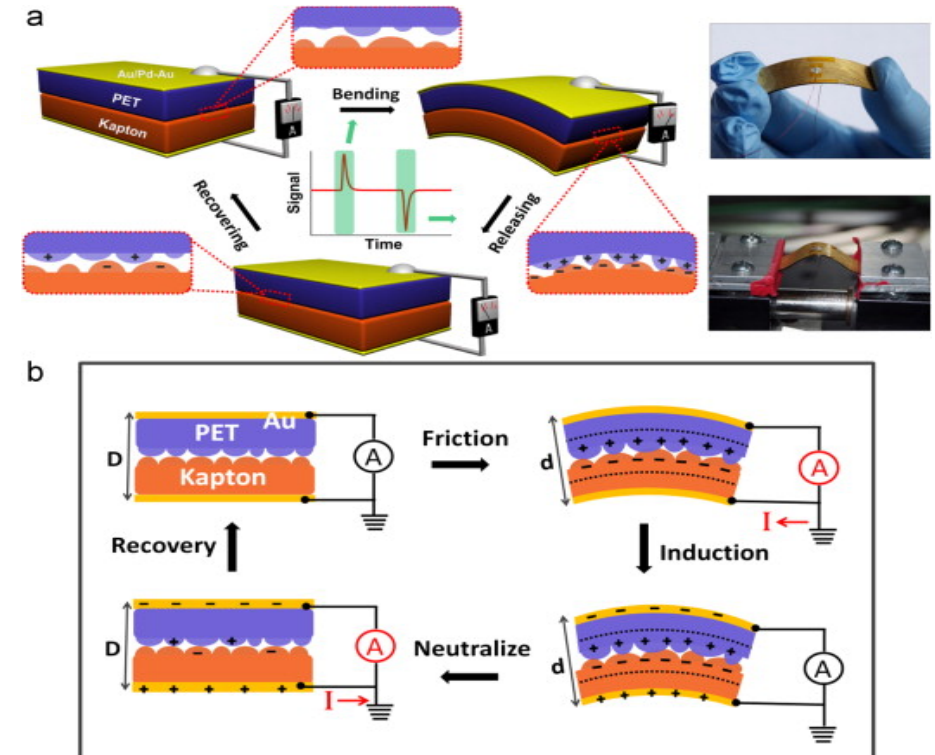


Suitable Micro Power generators for the MPU assembling



PZT Generator – 5-10 V at low amplitude

designed for
 -50...+150 °C operating temp. range
 -150...+200 °C shelf temp. range



Triboelectric generator (TENG) – up to 500 V

designed for
 -50...+150 °C operating temp. range
 -150...+200 °C shelf temp. range

High Level Overview

Product Manufacturing Flow

The tyre embedded RFIDD PI

Coatings and Inks

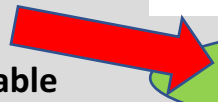
Adhesives

Software

Substrates

RFID bare die

Digital Screen production
SSLs R2R with fully customisable
patterning using UHMW PE substrates



1) Digital of Screens

Roll to Roll inline printing



2) High Speed Printing

Rfid assembly line

Meuhlbauer R2R line, Adhesive
jetting, flip-chip bare die placement
& thermode bonding



3) Adhesive dispense, die placement and bonding

Coating pre-treatments

BeneQ R2R ALD direct encapsulation,
VDL R2R 'Magenta' coating line
Nilpeter R2R printer



4) Coating pre-treatments

Lamination, Slitting, singulation

Meuhlbauer R2R 60000 converting l



5) Lamination, slitting and cutting

Rf & Materials Modelling, Simulation,
ICT system development

END USERS: By introducing additional sintering and polling stations in line it will be possible to produce EH and ES devices

Regulatory compliance, Standards, Life Cycle Analysis, waste stream management

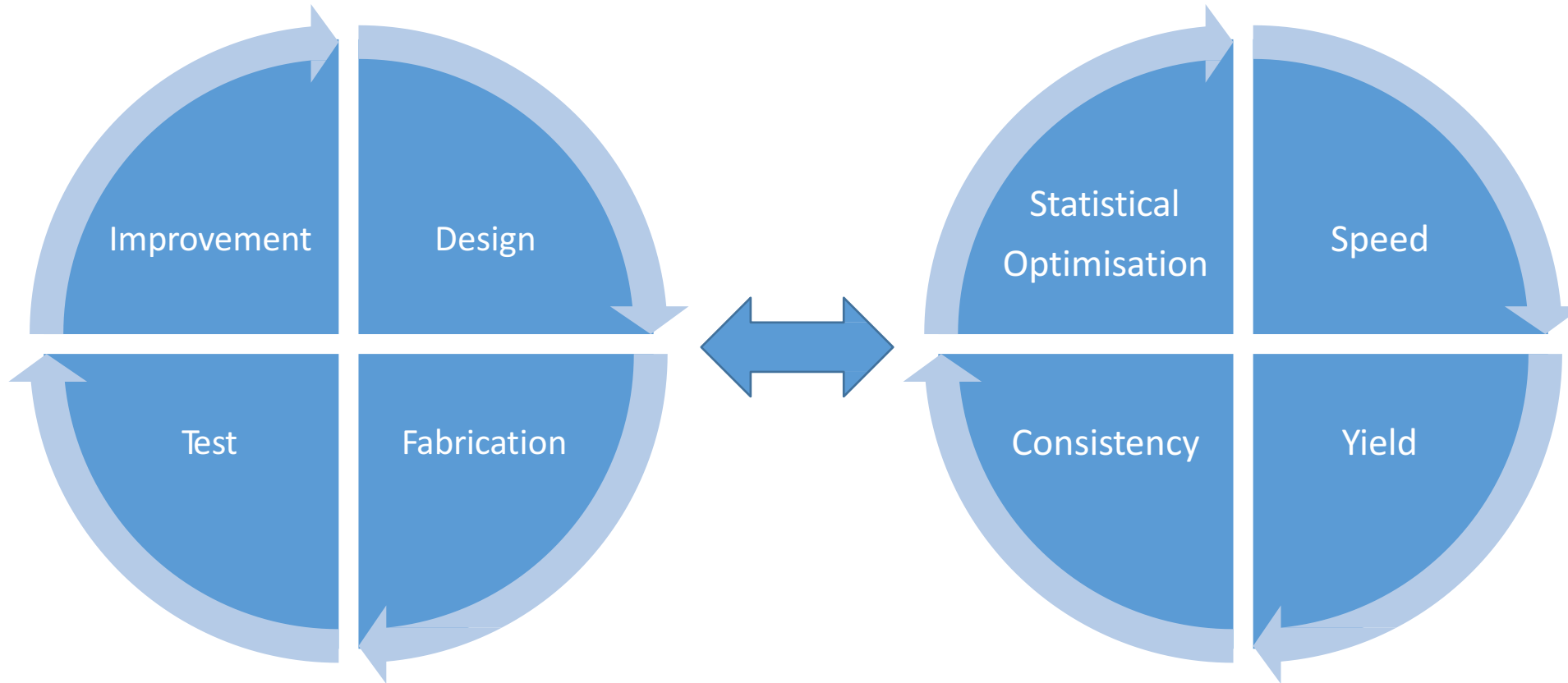


Development philosophy

2) Roll-to-roll printing

Batch tool production

Pilot Roll-to-Roll tool production

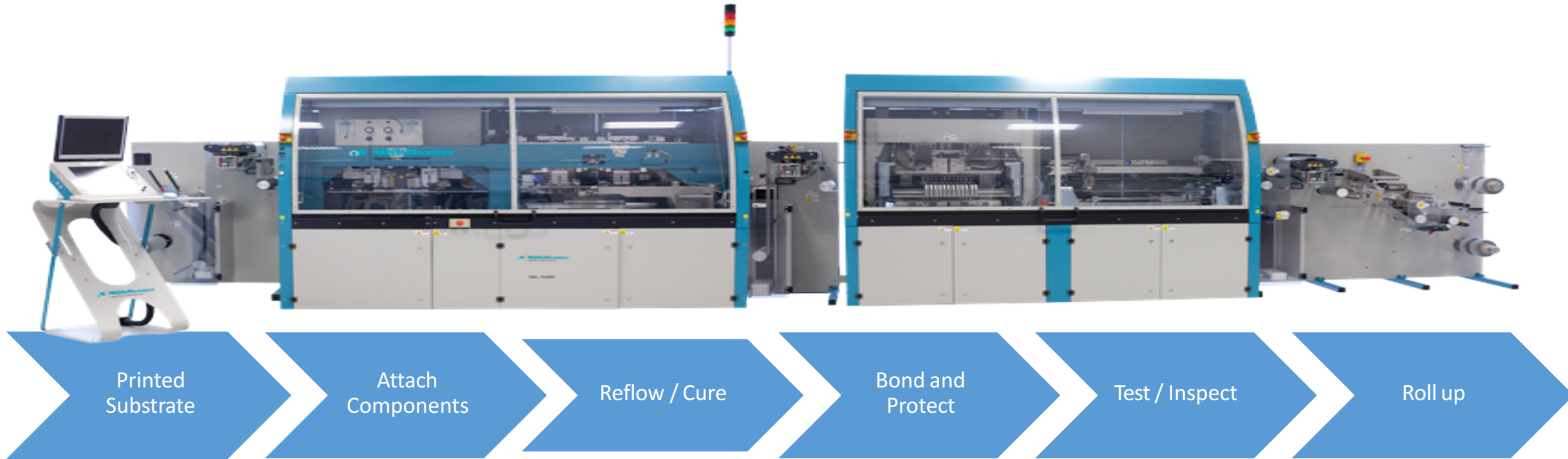


Develop and optimise in batch and then transfer to R2R manufacture

Batch tools mirror R2R tools for easy technology transfer



1) RFID Assembly line



- Conductive adhesive deposition
- Bare die pick and attach
- SMT conventional and thin film components
- Component encapsulation with UV cure

- Addressing manufacturing challenges:
 - High speed R2R integration
 - Integration of thin film electronics
 - Integration with packaging & moulded products



2) Encapsulation & Coatings

- Direct Encapsulation using ALD coating
- R2R printing of overlayers for adhesion promotion



BeneQ R2R ALD



VDL 'Magenta' coating line



3) Converting line for flexible products

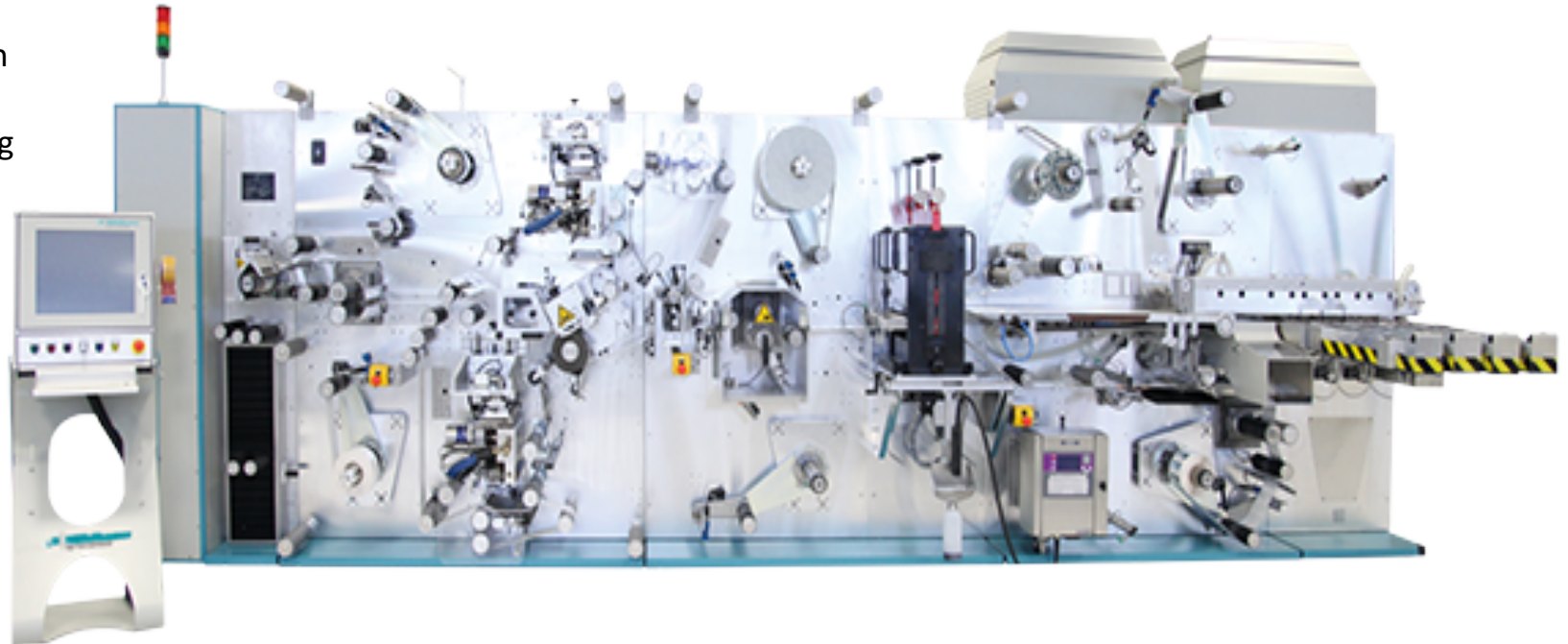
- Production of inlays and laminated products

WORKSTATIONS

- Unwinder for dry and/or wet inlay
- Unwinder for top and bottom material
- Top and bottom material registration and lamination
- Rotary die cutting unit
- Test module for functional test incl. bad unit marking
- Upwinder

CONFIGURATION FLEXIBILITY

- Transfer Adhesive or Hotmelt
- Bad Inlay Reject
- Reel and Single Output
- Second Die Cutter
- 4 Layer Handling
- Performance Testing Inline
- Vision System
- Output test and marking HF and UHF



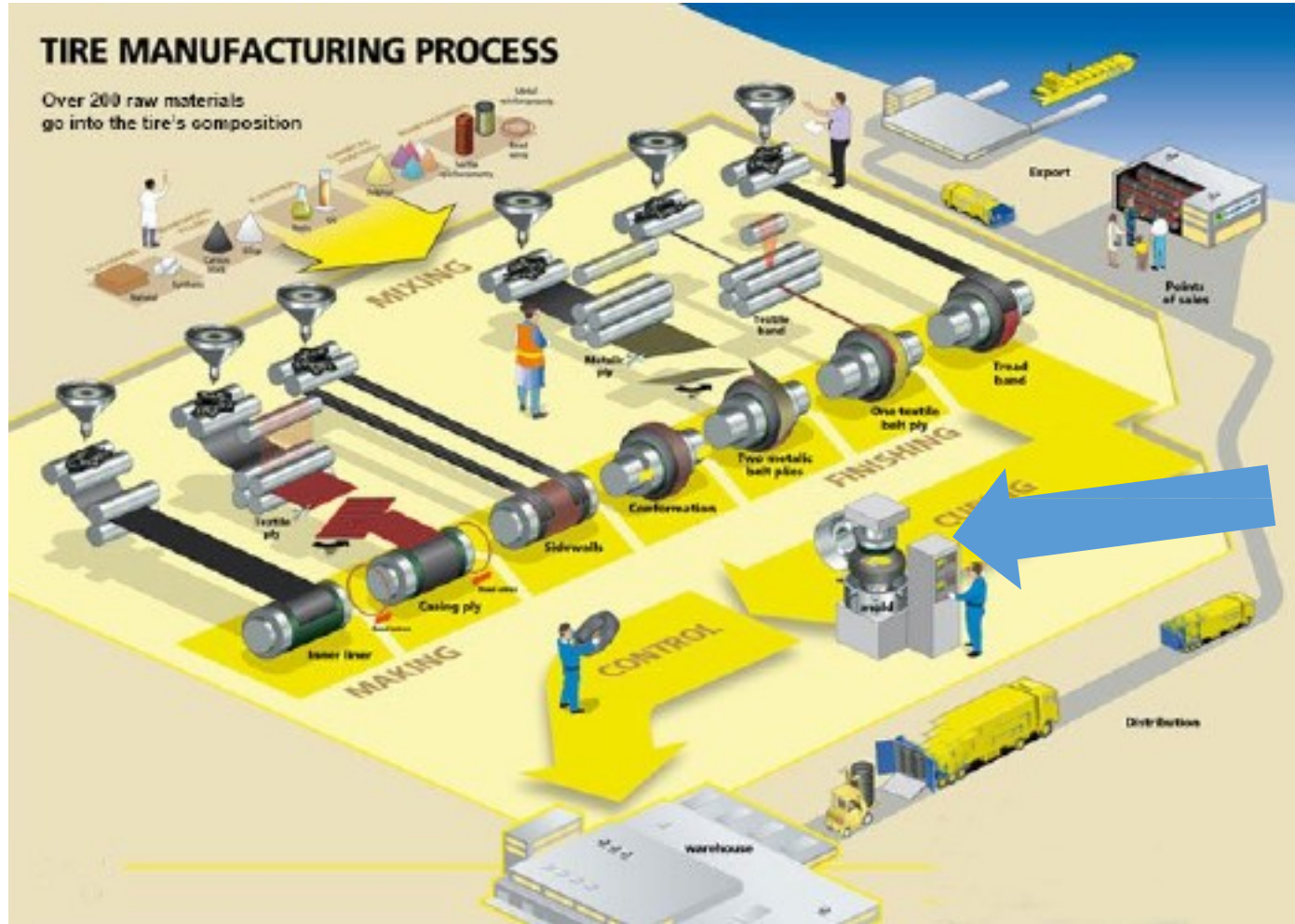
Meuhlbauer CL60000 converting line

Intended product

- UHF or NFC tags ready for tyre moulding process integration
- Available in reel or singulated format ready to be inserted into the tyre production line



RFID tag integration



SSL Rfid/NFC Tag integration during construction and curing phase

Robotic or hand integration before tyre curing step

