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- **Towards a Sustainable 6G**

    - **A Holistic Approach to Sustainability**

    - **An Example: The SUPERIOT Project**

Facts sheet

- National research flagship for **2018 – 2026** with a total volume of 250M€.

- 2nd phase started May 2022 – plan to continue until the end of 2028.

- Operated by **University of Oulu**.

- Currently involves 500 researchers from 50 nationalities.

- Steered the first 6G visions work via **13 6G White Papers** (downloaded over 1M times).

- Published 2640 per-reviewed papers and 89 doctoral theses.

- Over 400 company collaborators and more than 400 research projects so far.
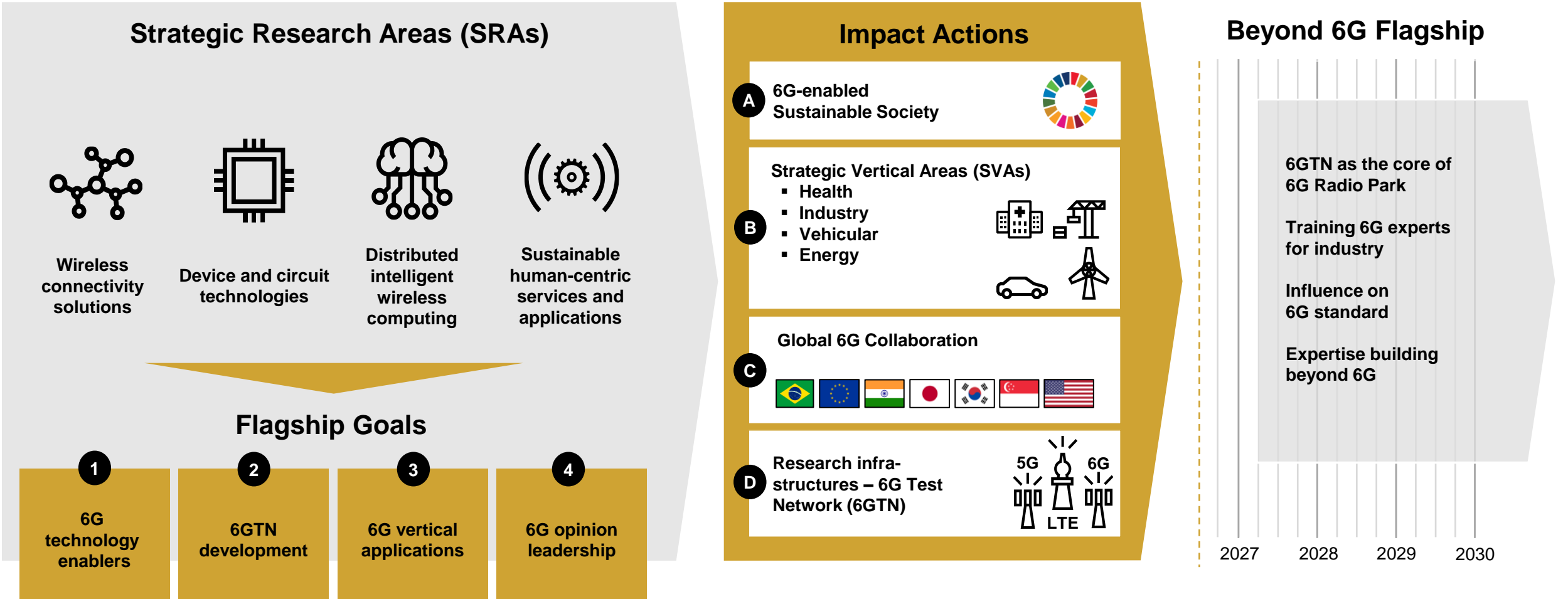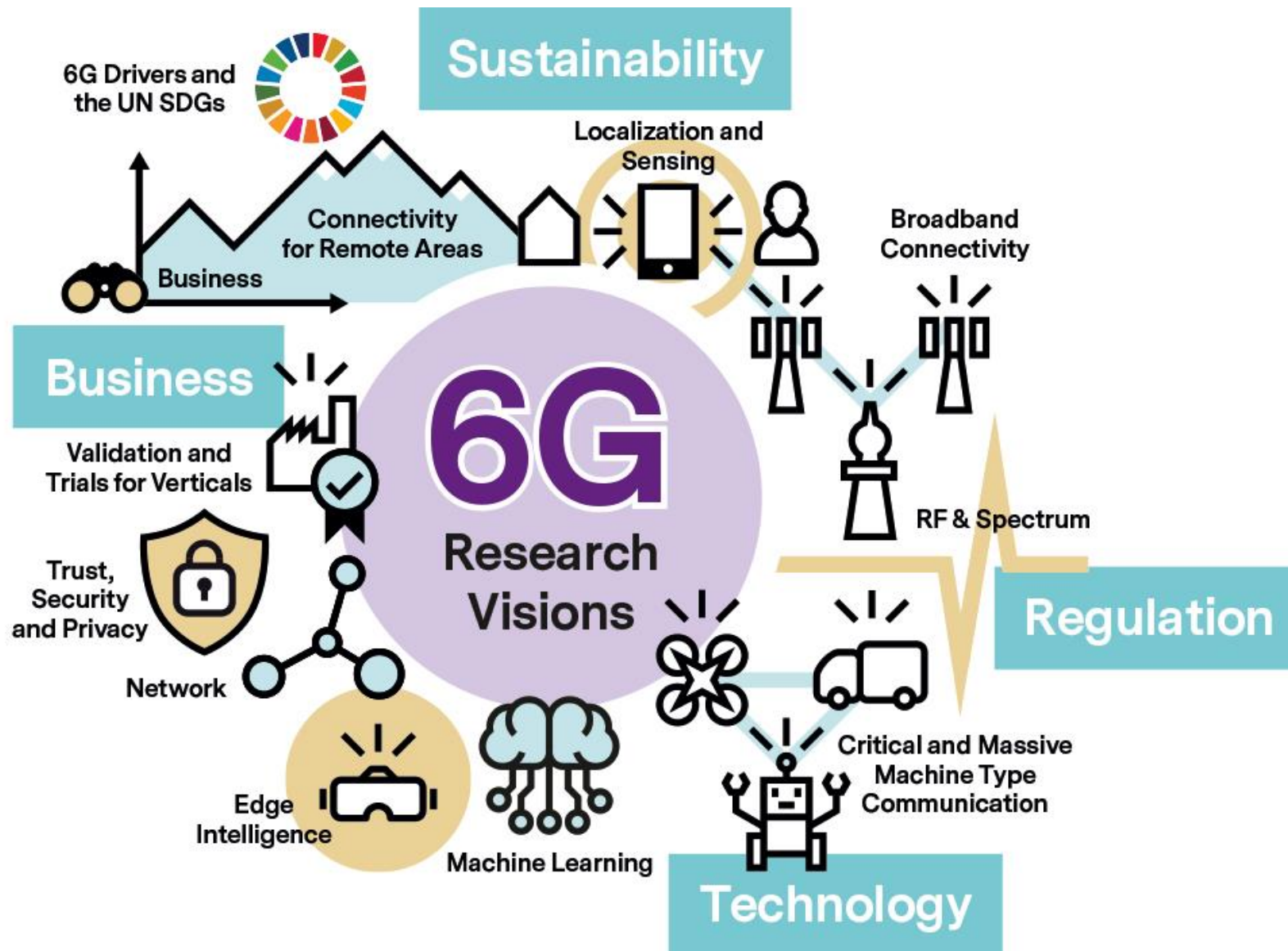
6G

VISION FOR 2030

A data driven society, enabled by near-instant, unlimited wireless connectivity

Overview

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6G Flagship Vision for 2030
Data-driven sustainable future society enabled by near-instant, unlimited wireless connectivity

Strategic Research Areas (SRAs)

Wireless connectivity solutions

Device and circuit technologies

Distributed intelligent wireless computing

Sustainable human-centric services and applications

Flagship Goals

1 — 6G technology enablers

2 — 6GTN development

3 — 6G vertical applications

4 — 6G opinion leadership

Impact Actions

A — 6G-enabled Sustainable Society

B — Strategic Vertical Areas (SVAs)
- Health
- Industry
- Vehicular
- Energy

C — Global 6G Collaboration

D — Research infra-structures – 6G Test Network (6GTN)

5G   6G
LTE

Beyond 6G Flagship

6GTN as the core of 6G Radio Park

Training 6G experts for industry

Influence on 6G standard

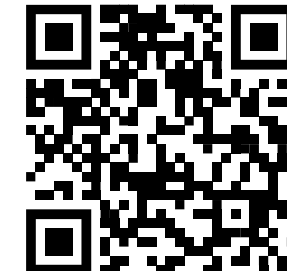Expertise building beyond 6G

2027   2028   2029   2030

6G Playground

The first-ever 6G white paper came out in 2019. Since then, other white papers have envisioned various future scenarios.

The 6G research visions will take you on a journey to explore the possibilities and imagine the opportunities in the 2030s.

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Towards a Sustainable 6G

6G FLAGSHIP
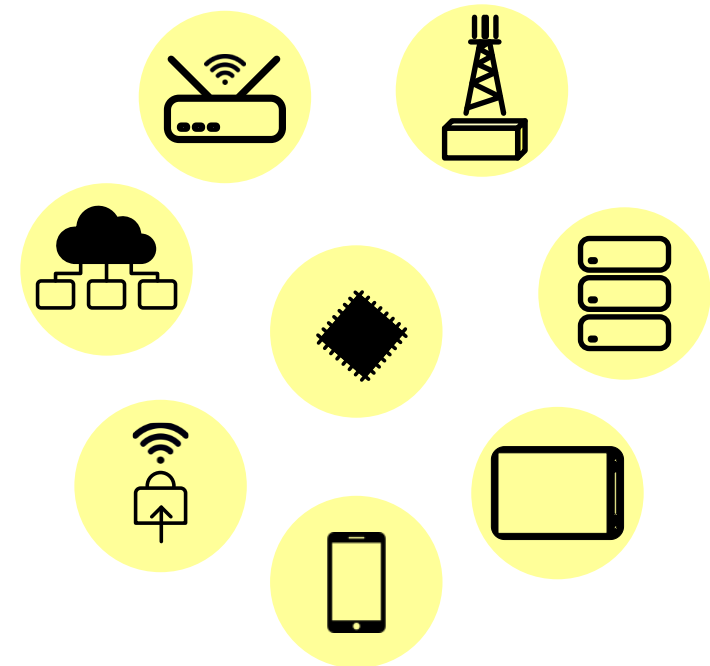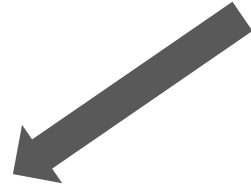
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Wireless Communication Systems

**Wireless Communication Systems
for Sustainability**

**Sustainable Wireless
Communication Systems**

Wireless Communication Systems & Sustainability
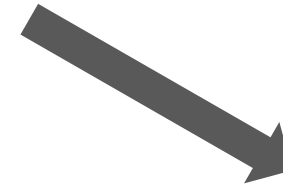
Wireless Communication Systems

Wireless Communication Systems for Sustainability

Sustainable Wireless Communication Systems

Wireless Communication Systems as a Part of the Solution

**Wireless Communication Systems as a Part of the Solution**

Wireless Communication Systems and their relationship to Sustainability

- What do we mean by **sustainable wireless communications** or in general **sustainability** when referring to wireless communication systems?

- Energy efficiency, low-power solutions, energy harvesting, spectral efficiency, etc. are important aspects of sustainable communications.

- In the past, we referred to this as **green communications**.

- How do we approach sustainability today? Sustainability needs to be approached from a wider perspective.

Creating a Truly Sustainable Wireless Communication System

A holisic approach to sustainability needs to be considered, taking into account all the stages of the life of a wireless communication system.

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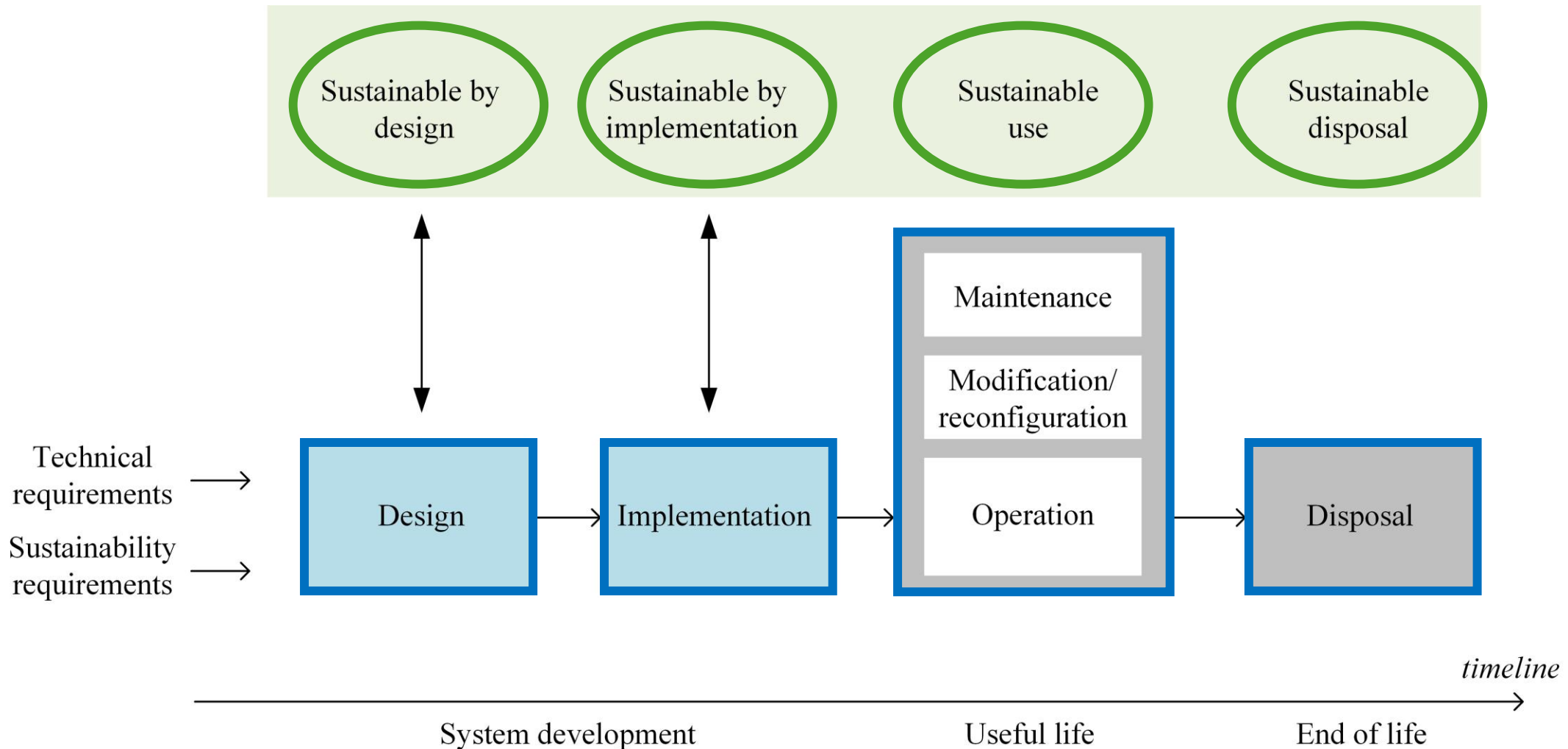
Sustainable by Design

- **Energy-Efficient Communications**
  - **Link-level:** modulation schemes, resource allocation, passive communications, wireless energy transfer, etc.
  - **Network-level:** MAC protocols, resource allocation, routing, wake-up techniques, wireless energy transfer, etc.

- **Spectral-Efficient Communications**
  - **Link-level:** modulation schemes, resource allocation, etc.
  - **Network level:** frequency reuse schemes, resource allocation, etc.
  - **Optical wireless communications**

- **Architecture:** sustainable network selection, etc.

Sustainable by Implementation

- **Implementaion based on environmental friendly technologies**
  - Use of common components
  - Use of printed electronics/biodegradable electronics
  - Use of abundant materials/elements
  - Use of ecological and durable parts
  - Use of recycled/recyclable parts
  - Avoiding the use of elements from conflict areas

- **Implementation based on sustainable manufacturing techniques**
  - Minimize environmental impact by
    - Operational efficiency by reducing costs, energy and waste
    - Energy and (natural) resource efficiency
    - Less pollution, emission, waste

Creating a Truly Sustainable Wireless Communication System

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Sustainable by Usage

- **Sustainable Operation**
    - Renewable energy sources
    - Energy autonomous solutions (batteryless operation) ← sustainable design
    - Energy-efficient and low power solutions ← sustainable design and implementation
    - Maintenance-free operation, remote maintenence
    - Modifiability / Reconfigurability

Sustainable Disposal/Reuse

- Environmentally-friendly electronic waste
- Repurposability
- Sustainable recycling

- **Methodologies for Developing Sustainable Communication Systems need to be developed**
  - Developing wireless communications systems (or key parts of them) that are sustainable by design.

  Holistic approach to sustainability:
  1) sustainable by design, 2) sustainable by implementation,
  3) sustainable by usage, 4) sustainable disposal

- **Methodologies for Sustainability Assesment:**
  - Developing metrics for sustainability.
  - How to measure sustainability in a communication system or part/functionality of it?
  - How to measure the impact of wireless communication systems on sustainability?

- **Sustainability and Standards**

6G FLAGSHIP

Example: The SUPERIOT Project

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SUPERIOT in a nutshell

SUPERIOT Consortium

Project fact sheet

Project number	101096021
Project name	**Truly Sustainable Printed Electronics-based IoT Combining Optical and Radio Wireless Technologies**
Project acronym	SUPERIOT
Call	HORIZON-JU-SNS-2022
Topic	HORIZON-JU-SNS-2022-STREAM-B-01-03
Type of action	HORIZON-JU-RIA
Project start date	1 January 2023
Duration	36 months
Total EC funding	4 757 739.50 €

Partnership: 10 partners, 1 associated partner

Involved countries: Belgium, Finland, Germany, Netherlands, Poland, Portugal, Spain and United Kingdom.

superiot.eu

The SUPERIOT Approach

- **SUPERIOT** offers a unique **holistic approach to sustainability**

  - **Sustainable by design**
    - Batteryless IoT devices, exploiting existing lighting infrastructure, highly flexible and adaptable, reconfigurability, similar solution can be used in different scenarios with different requirements, secure and reliable by design, etc.
  - **Sustainable by implementation**
    - Node design based on the use of printed electronics technologies.

- The concept is based on the use of both **radio** and **light technologies** to provide

  - **Dual mode wireless connectivity** (high performance, secure, reliable connections)
  - **Dual mode energy harvesting** (energy autonomy)
  - **Dual mode positioning** (robust and accurate localization)

SUPERIOT: Basic Principles

Sustainable by design   *Key advantages*

Multi-mode **communications**:   light- and radio-based wireless connectivity
1   *performance, adaptability, flexibility, energy efficiency*

Multi-mode energy **harvesting**:   light- and radio based
**2**   *energy autonomy, reliability*

Multi-mode **positioning**:   light- and radio-based
3   *robustness, accuracy*

Reconfigurability: at node and network levels
4   *adaptability, flexibility, repurposability, security, reliability*

Sustainable implementation: printed electronics technology (node)
5

Sustainable use: smart energy harvesting and management, batteryless IoT nodes, reconfigurability
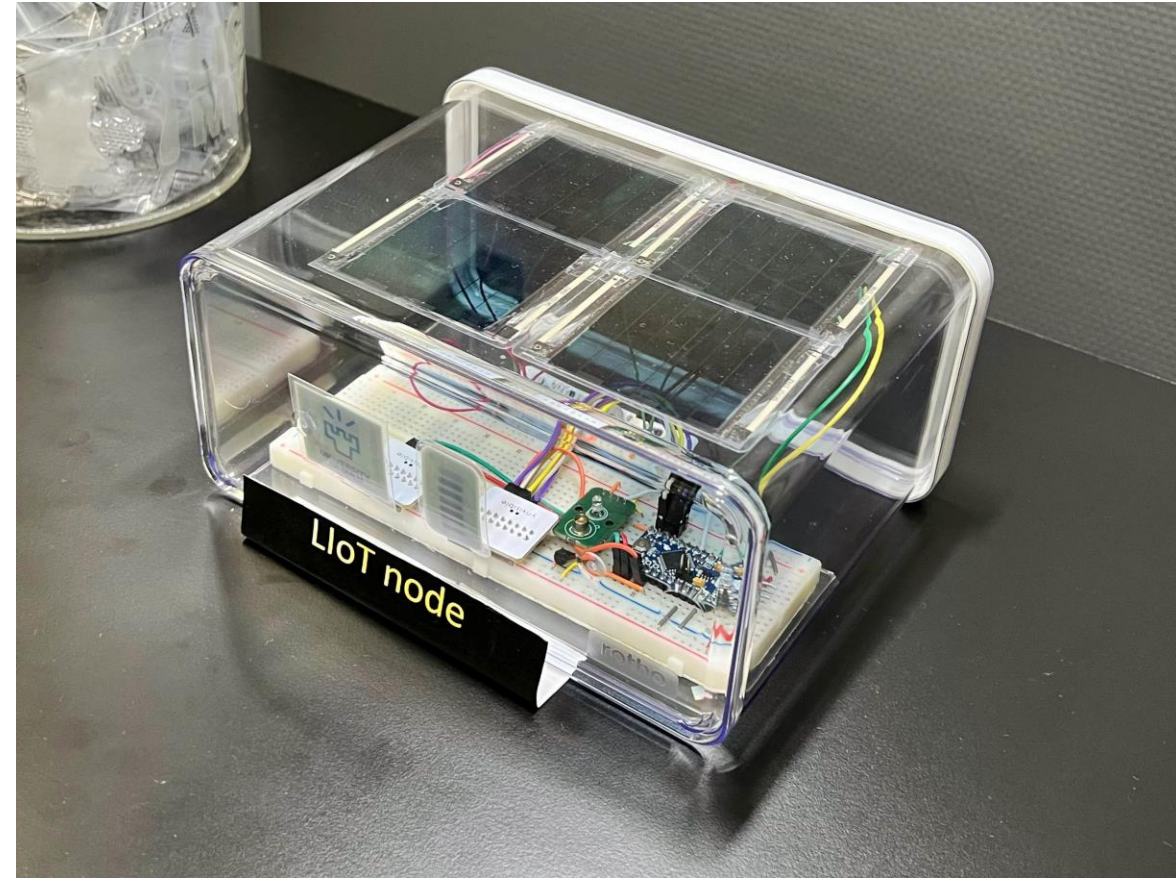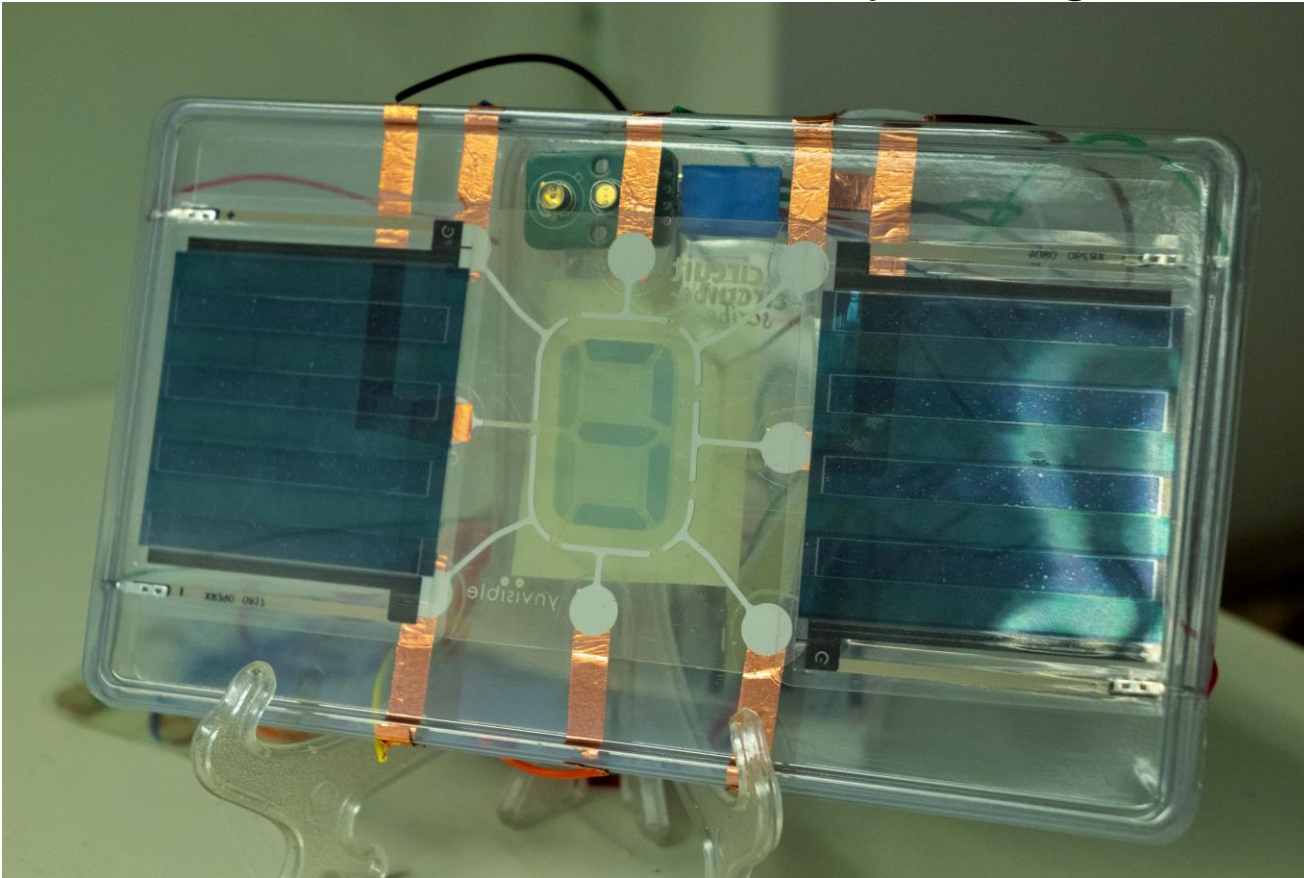
Sustainable disposal: printed electronics technology (node)
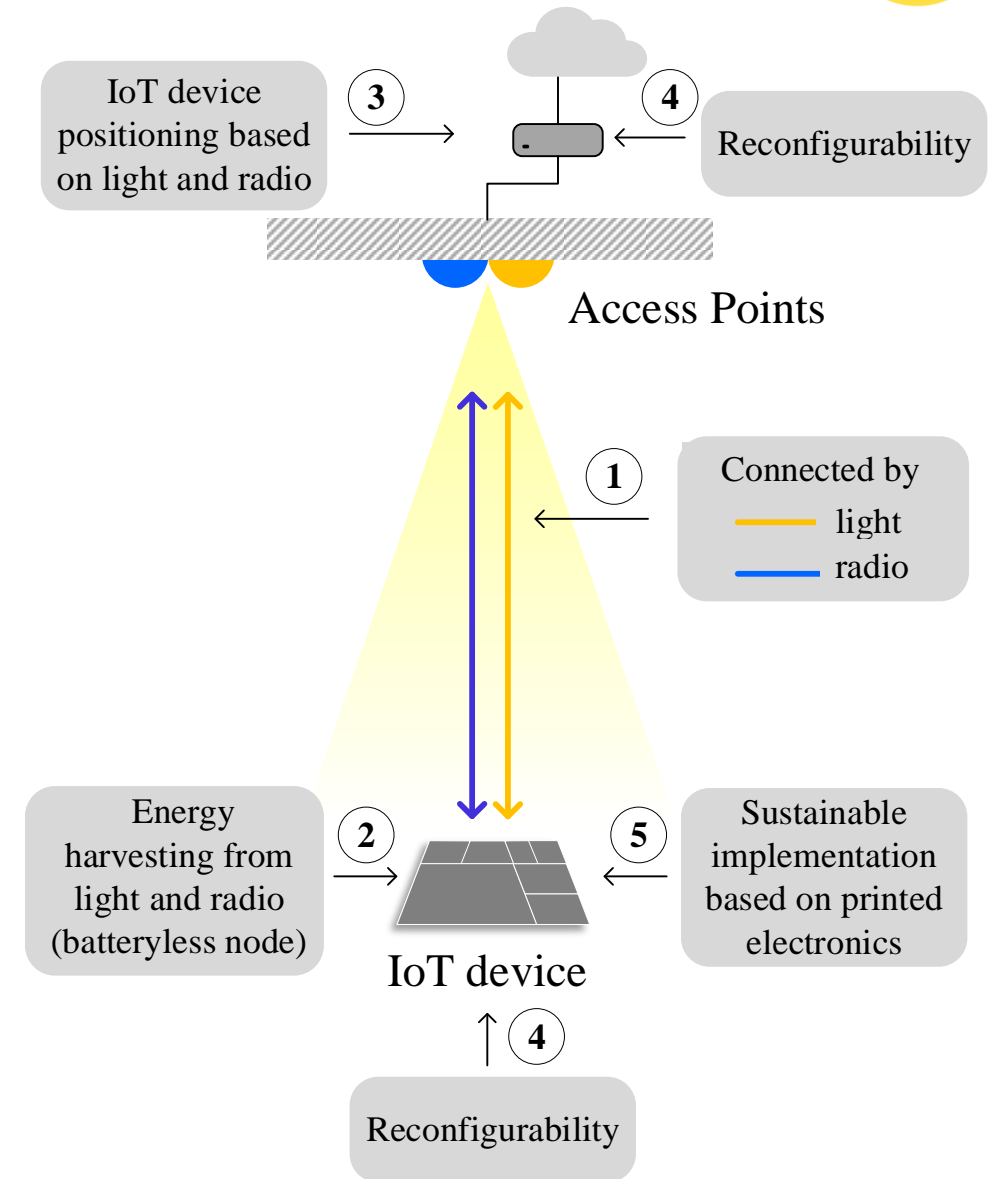
SUPERIOT: Initial prototypes

## Batteryless light-based IoT nodes @ CWC

- Printed electronics used in the implementations of the IoT nodes (e.g., printed solar cells, printed displays)
- Operation in downlink (visible light) and uplink (IR light)
- Sensors integrated in the design
- Additional printed components will be used in the project

SUPERIOT Demonstrators

1) Small reconfigurable IoT node (Hybrid technology)

2) Advanced IoT network for medical ICT scenarios

3) Small limited-capability IoT node (printed technology)

4) Large-area IoT node
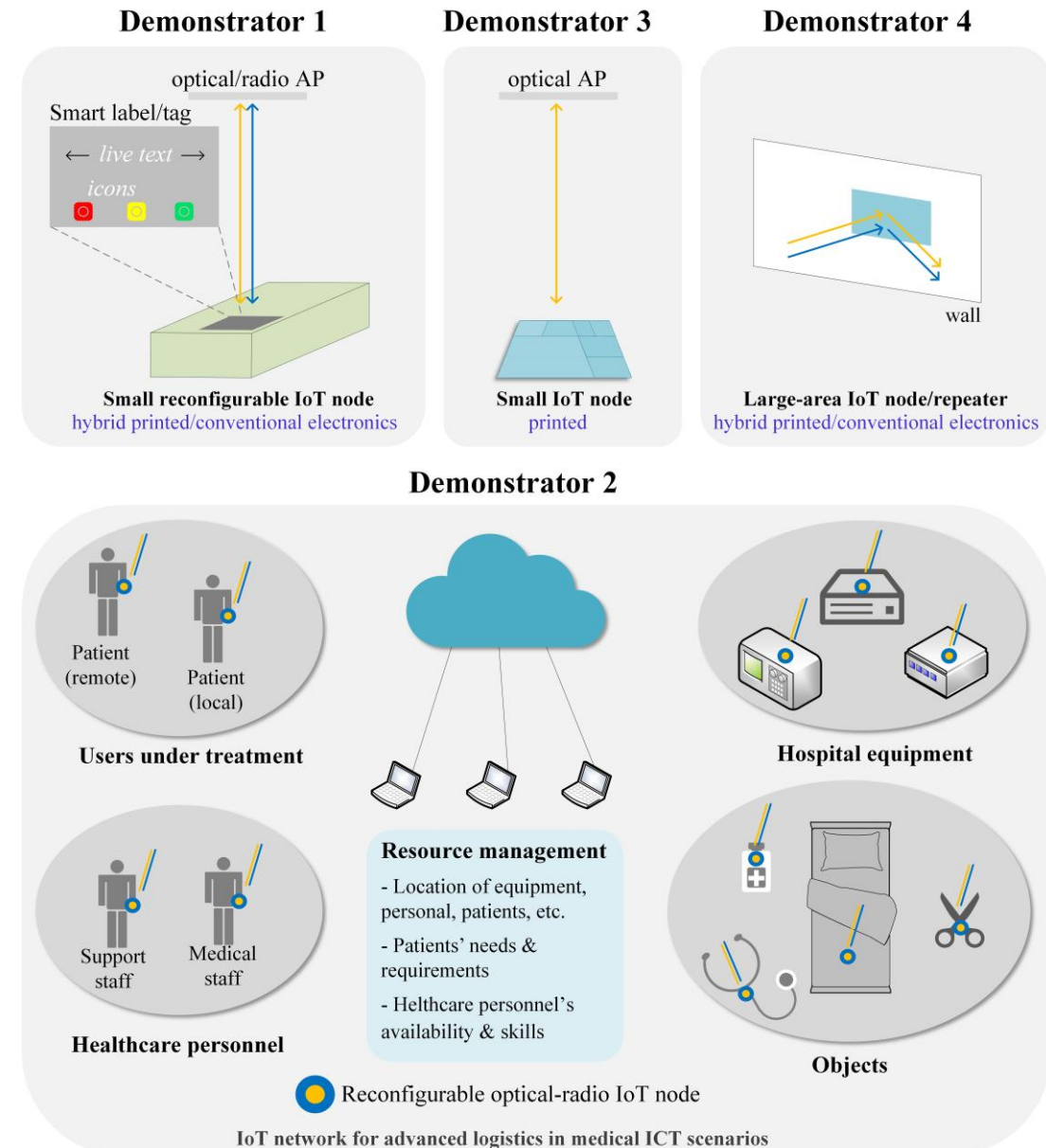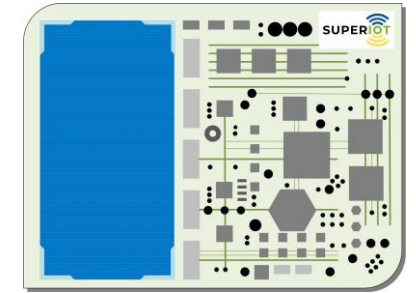
The SUPERIOT Visions

- SUPERIOT will develop a future-proof concept, paving the way towards novel technologies. In the next decade, we might see:

- **Fully-printed reconfigurable optical-radio IoT nodes**
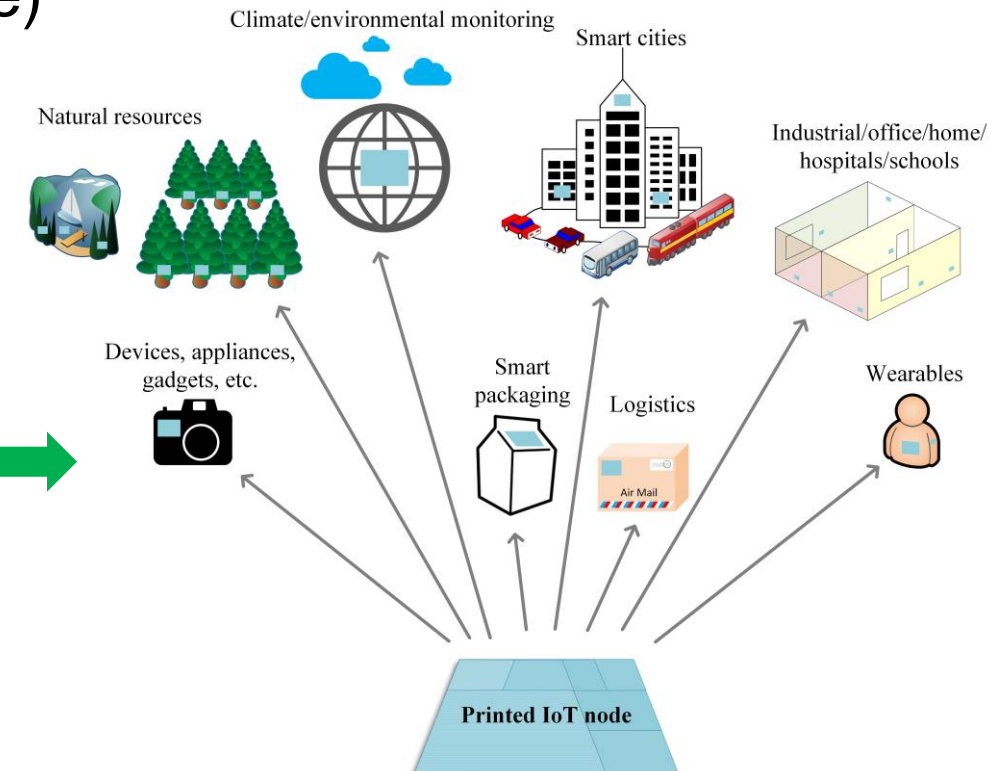
Sticker-like printed IoT node

- **Extremely inexpensive nodes** (e.g., one-cent node)

- **Environmentally-friendly disposable IoT nodes:** use of biodegradable electronics, etc.

- **Novel scenarios/use cases:**
  - **Massive sensing & massive actuation**
  - Inside the human body
  - Underwater
  - Mining, etc.

Climate/environmental monitoring

Smart cities

Natural resources

Industrial/office/home/ hospitals/schools

Devices, appliances, gadgets, etc.

Smart packaging

Logistics

Air Mail

Wearables

Printed IoT node

Conclusions

- Sustainable wireless communications is an emerging research area with high-impact in different areas.

- In order to develop truly sustainable wireless communication systems, we need to approach sustainability from a **wider perspective** and in a **holistic manner**.

- A clear and all-encompasing **definition of sustainability for wireless communication systems** as well as **metrics to quantify sustainability** are still missing.

- Creating **truly sustainable communication systems** could be seen as one of the key challenges for the future.

    - **IoT** could be used as an initial **realistic target communication system** to be developed as **truly sustainable.**

More than wireless.