

INEMI Roadmap Webinar: Sustainable Electronics

Watch a recording of the webinar

YouTube: <https://youtu.be/yiAR0myw1VU>

Other:

https://thor.inemi.org/webdownload//2025/Roadmap/Sustainable_Electronics_021325.mp4

Thomas Okrasinski (Nokia)

Fu Zhao (Purdue)

Francis Mullany (INEMI)

13 February 2025

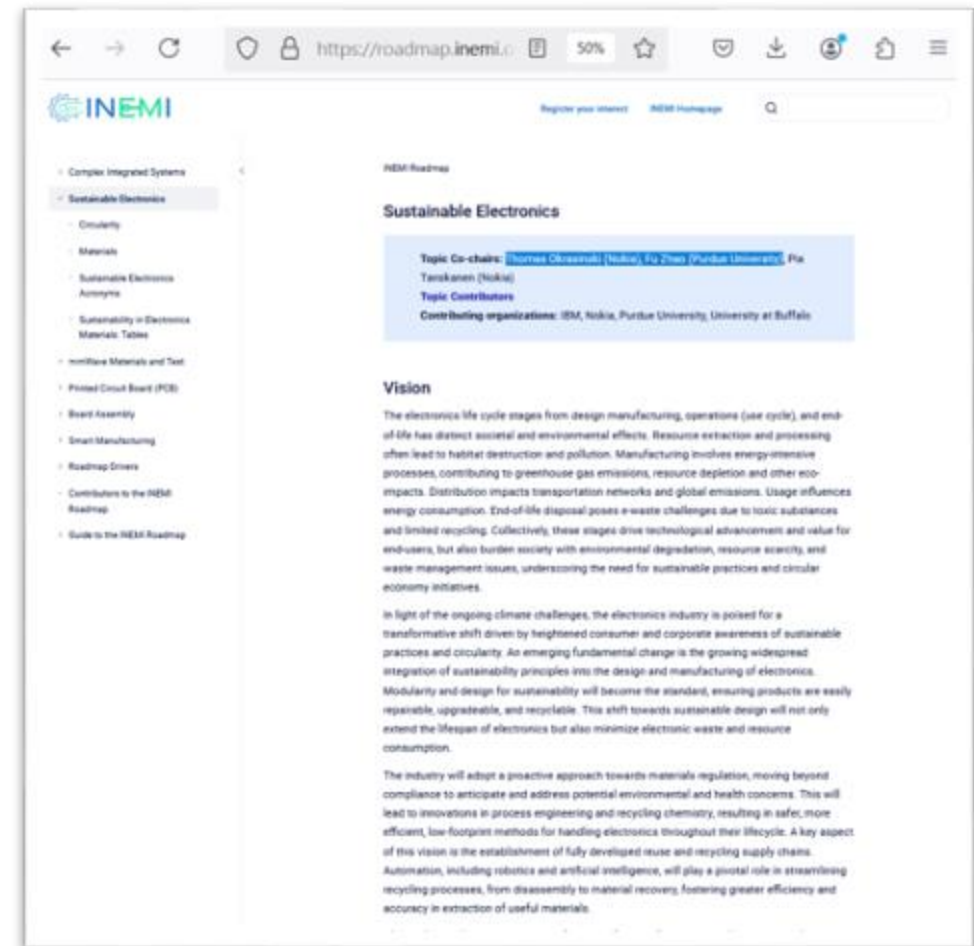


INEMI

CONNECTING MINDS
ACCELERATING INNOVATION

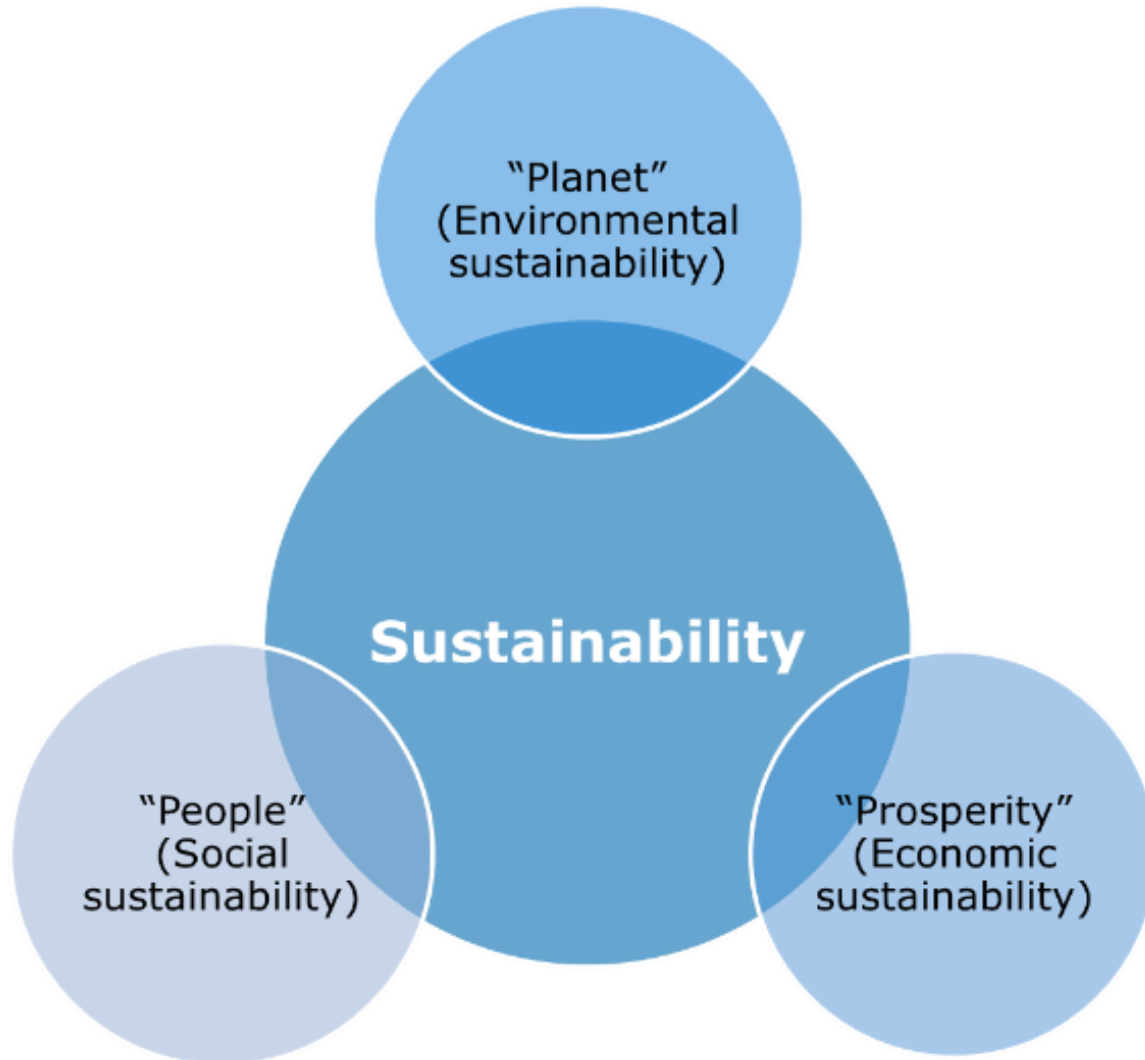
Agenda

- Review of current INEMI Sustainable Electronics Roadmap
 - Topics: Circularity, Materials
 - Thomas Okrasinski (Nokia), Fu Zhao (Purdue University)
 - 40 min
- Brainstorm: Energy, Water, Land Footprint
 - Focus on PCB manufacture and board assembly
 - Moderated by Francis Mullany (INEMI)
 - 20 min



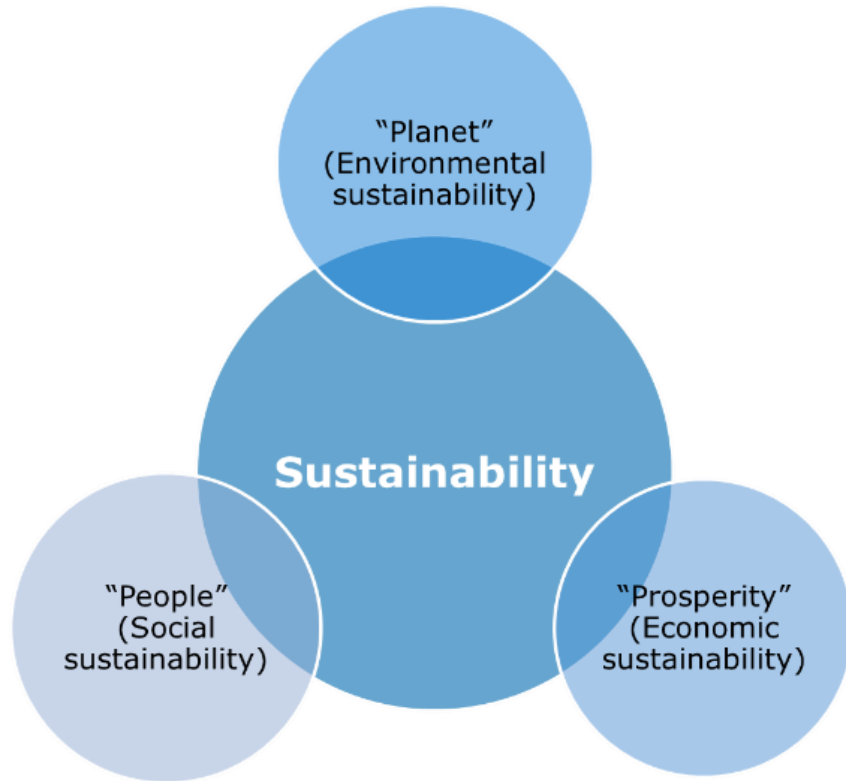
Review of the INEMI Sustainable Electronics Roadmap

Scope of Sustainability



Economic viability is closely intertwined with environmental and social impact.

Sustainability: Key Stakeholders



External drivers

- Customers & end users
- Shareholders
- Regulatory agencies, governments

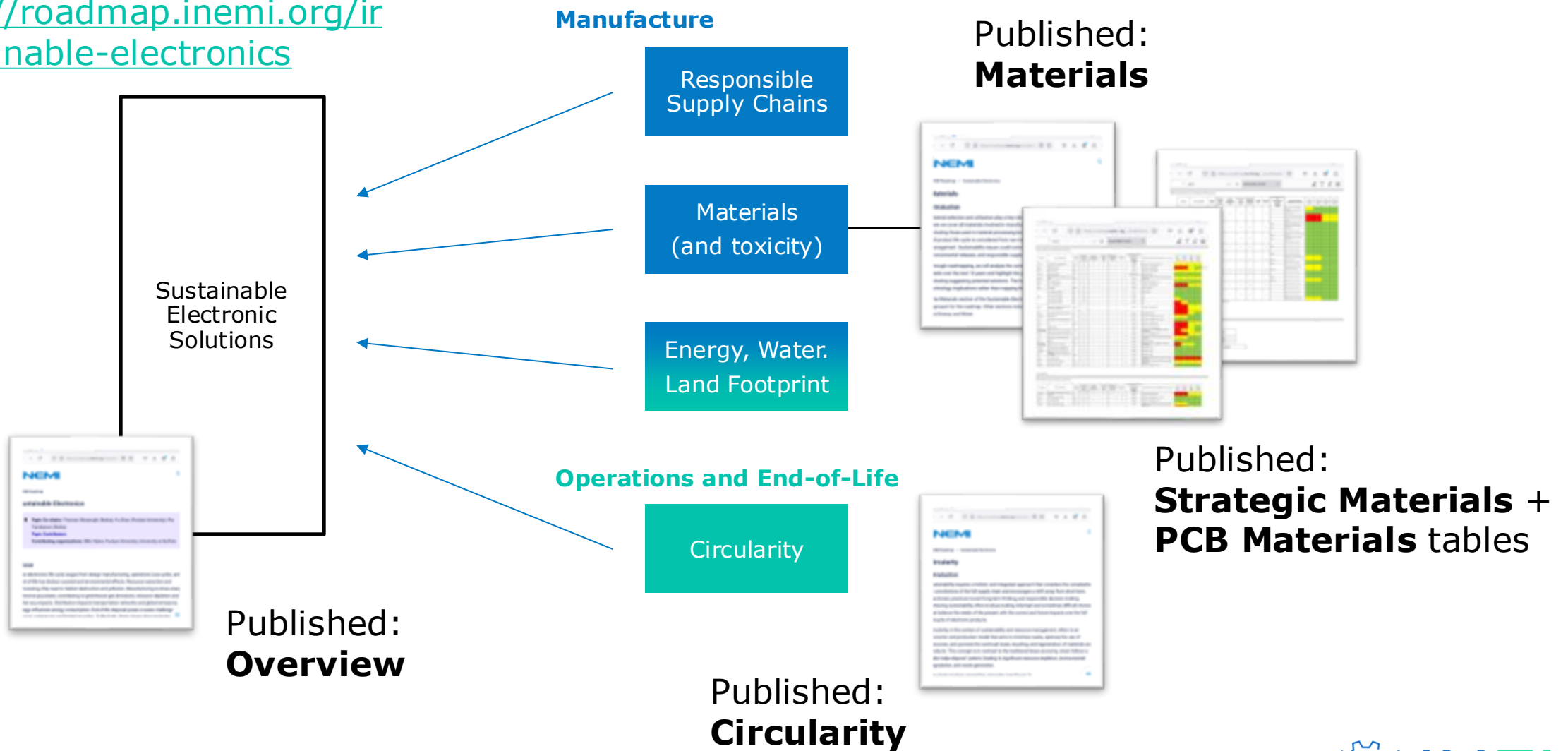


Industry

- OEMs and EMSs
- Component & material suppliers
- Reusers, refurbishers and recyclers

iNEMI Roadmap: Sustainable Electronics, Published Topics

<https://roadmap.inemi.org/ir/sustainable-electronics>



Electronics Industry: Reactive Responses v. Proactive Action

Reactive

Key issues requiring industry responses:

- Extending the use of digital product passports
- Regulatory push to phase out PFAS materials

Proactive

The industry should build sustainability into product design & manufacturing before regulatory intervention:

- Proactively identify future issues for existing materials
- Select new materials with environmental criteria at the forefront, e.g.
 - Avoid toxicity
 - Reduce greenhouse gas emissions
 - Improve circularity



Managing Materials in the Electronics Manufacturing Supply Chain

Industry action needed to ensure availability and control of critical materials:

- Electronics relies on many materials that are subject to supply chain disruption: The challenge is to build a secure and socially responsible supply chain.
- Electronics is a relatively small market for some materials – need a common industry voice to aid cross-supply chain coordination.
- Extend the concept of the digital product passport to include information to aid end-of-life processes, such as recycling.

Extraction



A.Savin, Wikipedia

Material supplier



Goku4711

Electronics manufacturing



Simplified
supply
chain



Key Materials Tables

Lists of key materials for electronics:

1. Key elements
2. Key compounds for PCB manufacturing
3. PFAS materials used in PCBs, cabling and connectors [in progress]

Tables outline for each:

- Any eco-sustainability issues
- Key recycling/reuse technologies
- Potential Substitutes [for PFAS] and
- Their technical readiness levels over time.

Materials sustainability tables

MATERIAL	USE IN ELECTRONICS	AMOUNT USED	POTENTIAL RECOVERY VALUE (HIGH/LOW)	MATERIAL AVAILABILITY CONSIDERATIONS (Y/N)	ELECTRONICS USE DOMINANT (Y/N)	RESPONSIBLE MATERIAL EXTRACTION (Y/N)	Toxicology issues	REPORTABLE (Y/N)	CIRCULARITY PATHWAY- "4Rs": 1&2 Reuse [product, component], 3 Refurbish, 4 Recycle	SOLUTION/TECHNOLOGY DESCRIPTION TO ACHIEVE 4Rs	4 Rs TRL: TODAY -2023	4 Rs TRL: 3 YEARS -2026	4 Rs TRL: 5 YEARS -2028	4 Rs TRL: 10 YEARS -2033
Epoxy resins	Laminate dielectric material	High	Low	N	N	N	Y	N		Reduce waste through additive processes	7	8	8	9
										Grind & recover metal, burn or repurpose resin	8	8	8	8
										Replace with bio-degradable resin	1	3	5	6
										Solutions to extract and reuse the epoxies	1	3	5	6
Sulphuric acid	Cu plating and micro-etchants (Cu)	High	Low	Y	N	N	Y	N	Reduce	Improved consumption control (e.g. with lower concentrations)	9	9	9	9
									Reuse	Repurposed for other industrial applications	9	9	9	9
										Waste treatment & disposal	9	9	9	9

Materials: Key Recommendations

The electronics manufacturing industry needs to

1. Understand better what materials it is using and their eco-impact.
2. Drive the development of new materials and processes for appropriate material substitution.
3. Push for reduced disparities between different regions and even states' regulations.
4. Push for homogenization of the extent of regulation and its enforcement across all scales of companies, without pushing small to medium enterprises (SMEs) out of business.
5. Enhance sustainability through improved supply-chain visibility, e.g. digital product passports.
6. Collaborate in supporting sustainable supply chains (e.g. tracing and global audits for conflict minerals, their extraction and their smelting).

Material science

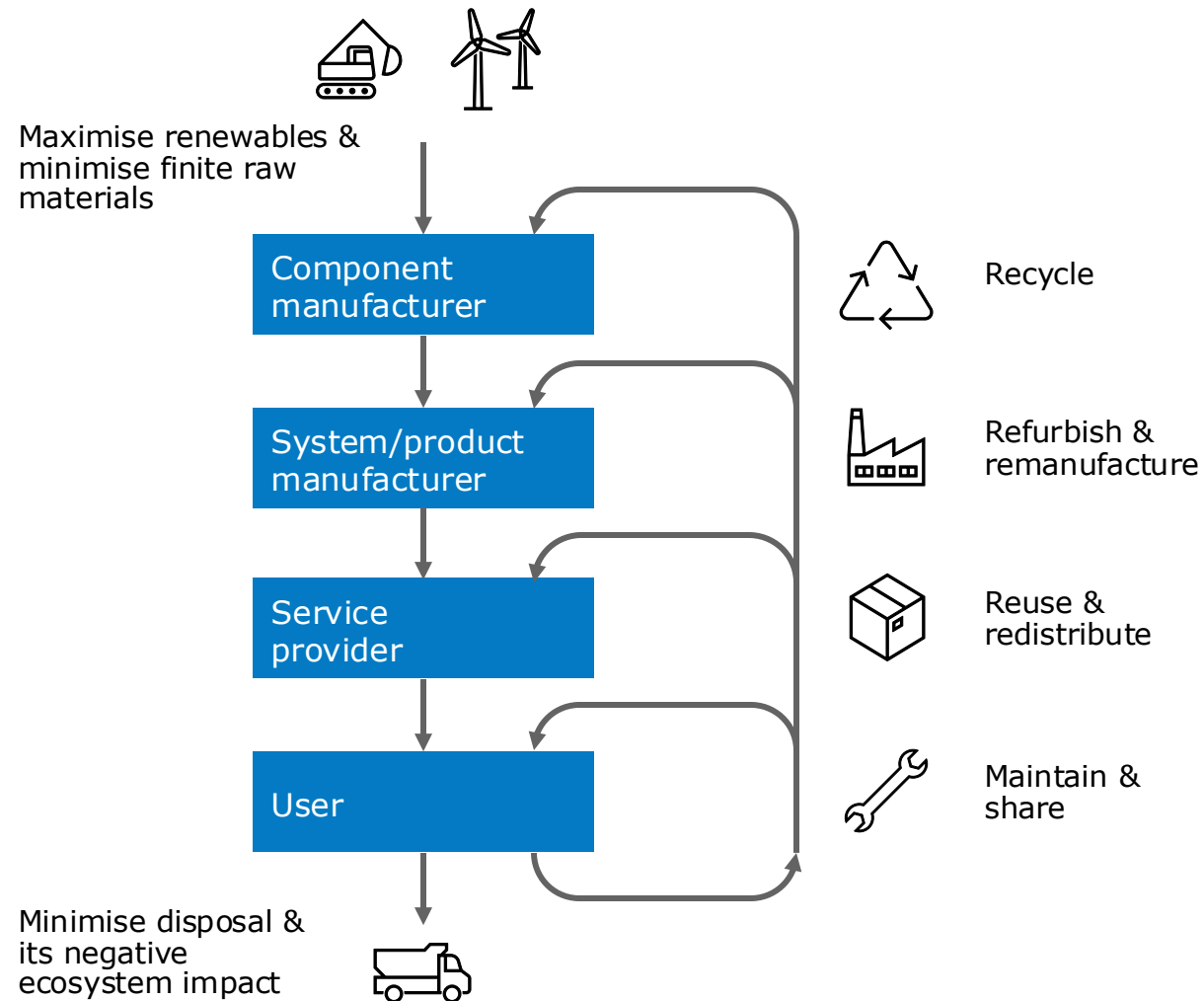
Homogenization of regulation

Supply chain

Circularity

Key Principles of Circularity for Electronics Goods

Ellen MacArthur Foundation butterfly diagram: Technical cycle



- Design for Longevity
- Reuse and Repair
- Remanufacturing
- Recycling
- Resource Efficiency
- Sharing Economy
- Bio-based Materials
- Intelligent Digital Solutions

Solutions [1/3]: Technology for Separation in Recycling

Solution	TRL in 2023	TRL in 2026	TRL in 2028	TRL in 2033
<i>Regulations</i> on materials composition of electronic products as part of the digital product passport	6	7	8	9
<i>Industry standards</i> on materials composition as part of the digital product passport	5	6	7	8
Full-spectrum inspection with AI for electronics extraction from municipal waste	3	6	8	9
Robotics + AI for mechanical disassembly of electronics into valuable components	5	7	8	9
Deployment of separation technology world-wide	5	7	8	9

TRL = technology readiness level.

Red – in research. **Yellow** – in development. **Green** – in deployment.

Solutions [2/3]: New Market Structures & Business Models

Solution	TRL in 2023	TRL in 2026	TRL in 2028	TRL in 2033
Distributed, verifiable marketplace for the recycling and reuse of enterprise-grade equipment.	6	9	9	9
"Electronics as a service"/leasing model for high-end and enterprise equipment.	6	8	8	9
Carriers need to be involved to establish reverse logistics network for international shipments	8	8	9	9
Industry to establish single voice towards consumers, promoting sustainable microelectronics (right to repair, need to recycle, etc.), away from "dispose and buy"	2	8	9	9

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Solutions [3/3]: Design and Test for Repair, Reuse, Recycle

Solution	TRL in 2023	TRL in 2026	TRL in 2028	TRL in 2033
Modular design (including hot-swap ability), easy chip replacement, software updates, B2B	9	9	9	9
Right-to-repair B2C – modular designs achieving increased integration, functionality and physical integrity	6	7	8	9
Reliability testing standards, backed by modelling and testing	5	7	9	9

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Circularity: Key Recommendations

To meet or exceed these timelines, the electronics manufacturing industry needs to:

1. Establish and standardize metrics and methodologies suitable for circularity of electronics.
2. Research and develop technologies to support cost-effective reuse, remanufacturing, and recycling; find pathways for currently unusable and unrecyclable components.
3. Extend the current collection and recycling networks.
4. Make circularity a key component of the manufacturing business model, moving from product-oriented to service-oriented, e.g., towards electronics-as-a-service.
5. Adopt product design for circularity and develop supporting tool capabilities.
6. Create a single, strong industry voice to promote sustainable electronics practices to the public/consumers at large.

Brainstorming: Energy, Water, Land Footprint

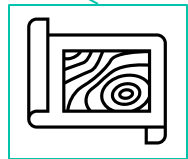
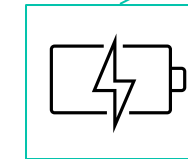
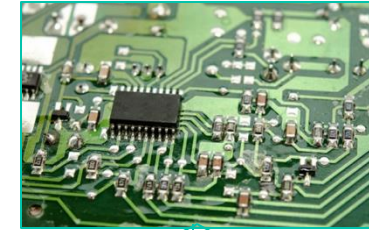
Download an Excel file with brainstorming inputs from all participants:

https://thor.inemi.org/webdownload//2025/Roadmap/Sustain_Electronics-brainstorm_021325.xlsx

Energy, Water, Land Footprint

Target:

- Focus on PCB manufacture and board assembly.
- Roadmapping
 - a) carbon-footprint reduction of production & input materials,
 - b) responsible water management, and
 - c) minimizing land footprint (biodiversity/geodiversity impact).



Status:

- Currently recruiting contributors.
Contributors do not need to be part of an INEMI member organization.

Expected scope of contributions:

- One-hour calls, held weekly. Minimal off-line work.

Contact fmullany@inemi.org if you or a colleague might be interested.