Subtopics Innovation Challenge 2026: Sustainable Chemistry and Electronics

1. Innovation in Design & Performance

a. Applying Eco-design principles: designing electronics for durability, repairability, recyclability, and modularity with focus on chemical and materials innovation
b. Design for disassembly: using adhesives, coatings, and encapsulants that can be safely removed or chemically dissolved.
c. Reducing material intensity while maintaining performance.
d. Developing more sustainable solders, recyclable encapsulants, and solvent systems for safer assembly/disassembly.

2. Innovations providing more resource efficient use or substitution of critical raw materials and toxic metal species

a. Alternative technologies for scarce and critical elements and critical nonrenewable resources (see Annex I a.) for details)
b. Use of abundant, non-toxic, recycled /recyclable feedstocks

3. Sustainable Manufacturing Approaches

a. Low-energy, low-waste fabrication methods (solution processing, additive manufacturing, green solvents).
b. Designing scalable, safer chemical routes generating less waste
c. Sustainable alternatives to hazardous reagents and byproducts (including additional technologies) (see Annex I b.) for details)
d. Development of biodegradable electronics components using polymers and organic materials.
e. Addressing social issues including child labor, unsafe working conditions, and other forms of injustice.

4. End-of-Life & Circularity

a. Chemical methods for disassembly, selective separation, and recycling
b. E-waste recycling and recovery of valuable materials
    i. Electrochemical recycling of materials in electronics (e-waste recovery of
    ii. metals like Li, Co, Au). Mechanical or chemical recycling of plastic materials in electronics
c. Use of recyclable, biodegradable (1) materials or materials that undergo full mineralization at end of life
    i. E.g. biomaterials based, biodegradable conductors and semiconductors.
d. Closed-loop systems
e. Prevention of material dissipation (2)

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[1] Biodegradation products should be well-characterized and understood. Ideally, these products should break down into simple, naturally occurring compounds that integrate harmlessly into ecosystems or at least be non-toxic, environmentally safe, and do not accumulate in soil, water, or living organisms. Knowledge of these degradation pathways helps prevent unexpected environmental impacts and supports sustainable chemical use.

[2] The smaller the amount of a given material used in a product, the more difficult it becomes to recover it later. Strategies aimed at reducing material usage may seem more sustainable at first, as they decrease immediate demand. However, this approach can be less sustainable in the long term, especially if technologies for effective recovery do not exist.
When materials are present only in tiny amounts within complex mixtures of multiple materials, elements, or substances, their recovery becomes technically challenging or even impossible.
Therefore, while reducing material usage can provide short-term benefits, it may inadvertently lead to greater material dissipation and environmental impact over time.
Atruly sustainable approach should balance material reduction with the feasibility of recovery, ensuring that long-term circularity is achievable.

5. Alternative & Emerging Materials

a. Organic and polymer electronics

b. Advanced Materials for Electronics

i. 2D materials like graphene, MoS_2, and MXenes: Surface chemistry affects electronic and mechanical properties.

ii. Metal–organic frameworks (MOFs) and covalent-organic frameworks (COFs): Used in sensing, energy storage, and optoelectronic devices.

iii. Self-healing or stimuli-responsive materials for flexible electronics.

c. Sustainable alternatives to fossil-based plastic materials used in electronics, e.g.:

i. PVC for cables, insulation, flexible parts

ii. ABS for casings for computers, printers, TV's, keyboards, etc.

iii. PS for insulation PC for optical discs, lenses, protective covers,

iv. LED

6. Novel devices

a. More sustainable Energy Storage & Conversion Devices (Batteries, Supercapacitors, Fuel Cells)

b. Organic Electronics, Photonics & Optoelectronics (OLEDs, OPVs, Perovskite solar cells, Photocatalytic devices)

ANNEX I

a) Critical elements and toxic metal species to be substituted

i. Rare earth elements: neodymium, dysprosium, terbium for magnets, displays, lasers.
ii. Indium: indium tin oxide (ITO) for transparent conductive films.
iii. Gallium: GaAs, GaN semiconductors for LEDs, power electronics.
iv. Cobalt for lithium-ion battery cathodes.
v. Lithium & nickel as battery materials under increasing demand.
vi. Tantalum forcapacitors.
vii. Tin for solders (Sn-based alloys), often from conflict regions.
viii. Platinum group metals (PGMs)for catalysts and sensors.
ix. Lead (Pb): historically used in solders, glass, and ceramics (restricted by RoHS, but exemptions remain).
x. Mercury (Hg)for displays, switches, fluorescent backlights.
xi. Cadmium (Cd): CdTe and CdS in thin-film solar cells, quantum dots, pigments.
xii. Chromium VI (Cr^{6+}) for corrosion protection, plating.
xiii. Beryllium for connectors and thermal management (toxic if inhaled)
xiv. Silicon/silicone: e.g. semiconductors, transistors and microchips, silicone rubber and sponge for sealing inner circuits and processors to protecting them from heat, corrosion, moisture, and other conditions

b) Commonly used materials and chemicals to be substituted

i. Brominated and polybrominated flame retardants (PBDEs, TBBPA, etc.) forcircuit boards, plastics (persistent, bioaccumulative).
ii. Phthalates: plasticizers in cables and casings (endocrine disruptors).
iii. Strong acids and bases: HF, HNO_3, H_2SO_4 (etching, cleaning).
iv. Chlorinated solvents: trichloroethylene (TCE), dichloromethane (degreasing,
v. N-methyl-2-pyrrolidone (NMP): solvent in battery and photoresist processing (toxic to reproduction).
vi. Dimethylformamide (DMF), dimethylacetamide (DMAc): solvents for polymer processing.
vii. Per- and polyfluoroalkyl substances (PFAS): in photoresists, lubricants, and coatings (persistent “forever chemicals”).
viii. Cyanides: electroplating of gold and other metals.
ix. Phthalates (e.g. Di(2-ethylhexyl) phthalate (DEHP), Dibutyl phthalate (DBP), Benzyl butyl phthalate (BBP), Diisononyl phthalate (DINP)

Supplementary materials & notes

Flame Retardants in Electronics

Category	Conventional Chemicals	Problems	Sustainable Alternatives	Benefits of Alternatives
Brominated flame retardants (BFRs)	PBDEs (penta, octa, deca), HBCD	Persistent, bioaccumulative, toxic, release dioxins/furans during e-waste burning	**Phosphorus-based** (phosphates, phosphonates, phosphinates), **nitrogen-based systems**	Lower toxicity, reduced persistence, effective flame suppression
TBBPA (tetrabromobisphenol A)	Widely used in Endocrine PCBs disruption	potential, leaching	**Reactive phosphorus flame retardants, intumescent systems**	Chemically bound → less leaching, can be integrated into polymer matrix
Additive BFRs (plastic housings, connectors)	Mixed brominated organics	Easily migrate from polymer, contamination in recycling streams hydroxide,	**Mineral fillers** (aluminum hydroxide, magnesium expandable graphite)	Inert, non-toxic, improve recyclability

Phthalates in Electronics

Category	Conventional Chemicals	Problems	Sustainable Alternatives	Benefits of Alternatives
High-volume plasticizers in PVC	DEHP, DBP, BBP, DINP, DIDP	Endocrine disruption, reproductive toxicity, not bound → leach into air/dust	**Adipates, sebacates, terephthalates**	Lower toxicity, better safety profile
General cable/plastic flexibility	DEHP in wires, connectors, casings	Banned under EU RoHS, still used elsewhere	**Citrate esters** (e.g., tributyl citrate, acetyl tributyl citrate)	Bio-based, biodegradable, safe for contact applications
PVC-based components	PVC + phthalates	Recycling difficulty, chlorine (polyethylene, → dioxins when burned	**PVC-free polymers** (polypropylene, polypropylene, TPU, bio-based plastics)	recyclable, less toxic lifecycle

Solvents used in electronics

Solvent	Toxicity	Hazards	Environmental Risks	Purpose / Application	Example Products
Acetone	Low to moderate; irritation, CNS effects at high exposure	Highly flammable; skin and eye irritant	VOC; contributes to air pollution	Cleaning and degreasing of components, removing flux residues	PCBs, semiconductor, wafers, connectors
Isopropyl Alcohol (IPA)	Low; skin and eye irritation, CNS effects at high concentration	Flammable; irritant	VOC; biodegradable	Cleaning PCBs, removing flux and residues	Smartphones, laptops, circuit boards, displays
Toluene	Moderate; CNS effects, respiratory irritation	Highly flammable; toxic by inhalation and skin absorption	VOC; toxic to aquatic life	Solvent for adhesives, coatings,and photoresists	LEDs, IC packages, flexible electronics
Xylene	Moderate; CNS effects, liver/kidney damage	Flammable; irritant	VOC; harmful to aquatic organisms	Cleaning, degreasing, solvent for resins and inks	Printed circuits, microelectronic assemblies, PCBs
N-Methyl-2-pyrrolidone (NMP)	Moderate to high; reproductive toxicity, skin absorption	Flammable; irritant; harmful if inhaled	Persistent in water; toxic to aquatic organisms	Photoresist strippers, solder mask removal	Semiconductors, advanced ICs, LCD displays
Dimethylformamide (DMF)	High; liver toxicity, reproductive toxicity	Flammable; irritant; harmful by inhalation and skin absorption	VOC; toxic to aquatic organisms	Solvent for polymers, resins, photoresists	Flexible circuits, polymer coatings, display films
Methanol	High; toxic by ingestion, inhalation, skin absorption; CNS CNS depression	Flammable; irritant	VOC; toxic to aquatic life	Cleaning, degreasing, thinner for inks/coatings	Batteries, PCBs, sensors
Ethyl Acetate	Low to moderate; CNS effects at high exposure	Highly flammable; irritant	VOC; biodegradable	Cleaning, degreasing, solvent for coatings and adhesives	Solder masks, electronic adhesives, display coatings

Solvent Propylene	Toxicity	Hazards	Environmental Risks	Purpose / Application	Example Products
Glycol Monomethyl Ether (PGME)	Low to moderate; irritation to eyes and respiratory system	Flammable; mild irritant	VOC; biodegradable	Photoresist thinner, cleaning agent	Photolithography processes, IC fabrication, printed electronics
Trichloroethylene (TCE)	High; carcinogenic, CNS depression, liver/kidney toxicity	Non-flammable; toxic by inhalation and skin	Persistent; toxic to aquatic organisms	Degreasing metal parts, cleaning PCBs (restricted use today)	High-precision connectors, metal housings, legacy electronics cleaning
Perchloroethylene (PCE / Tetrachloroethylene)	Moderate to high; liver/kidney toxicity, possible carcinogen	Non-flammable; irritant	Persistent; toxic to aquatic life	Metal cleaning, solvent in dry cleaning of electronic components	Semiconductor equipment parts, metal chassis, legacy PCB cleaning

Plastics used in electronics

Plastic	Typical Use in Electronics	Sustainability / Environmental Notes
PVC (Polyvinyl Chloride)	Cables, insulation, housings, flexible parts	Difficult torecycle; can release harmfulsubstances (dioxins, HCl) when incinerated; contains additives like plasticizers that may be toxic.
ABS (Acrylonitrile Butadiene Styrene)	Casings for computers, printers, TVs, keyboards	Durable and recyclable in theory, but mixed-material products complicate recycling; not biodegradable; energy-intensive production.
PC (Polycarbonate)	Optical discs, lenses, protective covers, LED housings	Can be recycled, but less common; potential BPA leaching; production is energy-intensive.
PS (Polystyrene)	Packaging, insulation, some housings	Lightweight, cheap, but difficult to recycle in electronic applications; can persist in the environment; often incinerated.
PP (Polypropylene)	Internal components, battery casings, connectors	Relatively easier to recycle; low toxicity; biodegradable only very slowly; lightweight, so energy savings in transport.
PE (Polyethylene)	Cable insulation, wire coatings, some housings	Widely recyclable, low toxicity; very durable and persistent in environment if not recycled.
Nylon (Polyamide, PA)	Gears, bearings, connectors, structural components	Strong and durable, recycling is limited; production is energy-intensive; not biodegradable.

Plastic	Typical Use in Electronics	Sustainability / Environmental Notes
PET (Polyethylene Terephthalate)	Insulating films, capacitor films, PCBs	Widely recyclable; durable; can accumulate in environment if not properly managed.
PBT (Polybutylene Terephthalate)	Connectors, switches, housings	Limited recycling options; durable; long lifespan but persistent in environment.
ABS/PC Blends	Casings and structural components	Same issues as ABS and PC; blending complicates recycling; long lifespan but energy-intensive to produce.