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Waste streams to material resources

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Type of the Paper: Editorial Corner.

For most of my career, I have watched waste be treated as an endpoint, something to be buried, burned, or shipped elsewhere. That framing is not just environmentally reckless, it is intellectually lazy. The materials we discard are not devoid of value. They are feedstock in the wrong place, at the wrong stage of the wrong supply chain. Waste valorization is the deliberate conversion of residues and end-of-life products into new, high-performance materials. This waste conversion is the most important materials frontier of this decade and the evidence is no longer anecdotal. According to the United Nations Environment Programme's Global Waste Management Outlook 2024, global municipal solid waste generation is projected to rise from 2.1 billion tonnes in 2023 to 3.8 billion tonnes by 2050. The report also estimates that a circular-economy pathway could deliver a net annual gain of USD 108.5 billion by 2050 [1].

The economics alone should command attention. Europe accounts for approximately 35.8% of the global waste valorization market, while municipal solid waste management represents 36.2% of end-user activity [2]. Italy's tyre recycling market, valued at $104.2 million in 2024 and projected to reach $124.8 million by 2029, illustrates how discarded materials can become a growing industrial resource [3]. Waste valorization is not charity, it is industrial logic.

But the opportunity extends beyond economics to architecture, ecology and even space. Construction and demolition waste represents a vast reservoir of recoverable materials, yet only 22% reportedly re-enters the economy [4,5]. Recovering aggregates and other constituents from demolished buildings could transform cities into their own quarries, reducing reliance on virgin resources. Similarly, forestry and agricultural residues offer feedstocks for bio-based materials and energy. With agricultural residues exceeding five billion tonnes annually worldwide, their conversion into useful products presents significant opportunities for resource recovery and more sustainable manufacturing [6]. The same principle applies to the ocean and beyond Earth. Persistent marine plastics expose the limitations of conventional waste management, prompting

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research into alternatives such as cellulose-based and algal-derived plastics [7,8]. In space, innovations including Japan's wooden LignoSat, which operated in orbit for 116 days, demonstrate how material selection can account for end-of-life behaviour as well as performance [9]. Cellulose-chitin composites and wood-derived materials are also being explored to reduce the environmental consequences of satellite re-entry. Although these technologies require further validation, they reinforce a fundamental principle that materials should be designed not only for how they perform, but also for what they can become after use.

The objective is not to convert every waste stream into a product regardless of cost or consequence. Some materials are contaminated, some recoveries consume excessive energy and some residues must remain in the environment to sustain ecological functions. Effective valorization therefore requires appropriate characterization, processing technologies and life-cycle assessment. The goal is to replace the linear logic of extraction, consumption and disposal with systems that retain material value for as long as possible. Ultimately, the waste of one system can become the raw material of another, provided that science, technology and industry are designed to make this transition possible.

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