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Sustainable Moisture Energy Harvesting and Self-Powered Sensing Interfaces via Hygroscopic Hydrogels

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Background
With the rapid growth of the Internet of Things (IoT) and wearable electronics, sustainable energy harvesting and multifunctional sensing are essential for autonomous, battery-free systems. Atmospheric moisture is a ubiquitous and underutilized energy source, but existing technologies suffer from limited stability and complex device integration.

Objectives
This study aims to develop two complementary moisture-driven energy platforms:
(1) a leaf-based energy harvester (LEH) for sustainable power generation [1], and
(2) a self-sustained energy harvesting and sensing interface (SEHSI) enabling continuous sensing and human-machine interactions [2].

Methodology
Natural fallen leaves were delignified, carbon-coated, and asymmetrically functionalized with hygroscopic iron hydrogel, forming LEHs with built-in water gradients for continuous power generation [1]. Separately, SEHSI was fabricated by integrating a nickel-based hygroscopic hydrogel encapsulated in polyvinyl alcohol on flexible ITO-PET substrates to harvest and confine ambient moisture [2]. Both systems leverage hygro-contact-ionic interactions to establish electrical double layers for sustainable energy output.

Results and Discussion
Once the hygroscopic hydrogel captured the ambient moisture, LEHs achieved a high short-circuit current density (49 $\mu A\ cm^{-2}$) and volumetric power density (497 $\mu W\ cm^{-3}$), enabling scalable 13 V panels for low-power electronics. Life cycle assessment showed significantly reduced environmental impact owing to the biodegradability and valorization of leaf substrates. In parallel, SEHSI delivered stable 0.32 V outputs for over four days once it captured and locked the moisture, and exhibited capacitive behavior, enabling multimodal sensing: tactile pressure detection, temperature response, humidity monitoring, and real-time breath tracking. Both platforms demonstrated excellent cycling stability (>120 cycles for LEH; >10,000 cycles for SEHSI) and compatibility with flexible, wearable applications.

Conclusions
By coupling sustainable substrates with hygroscopic hydrogels, we present sustainable energy and sensing systems that harvest ubiquitous atmospheric moisture for continuous operation. This integrated approach could benefit low-power electronics, wearable healthcare monitoring, and next-generation human–machine interfaces.

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