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Functional low-dimensional materials with judicious hetero- and single-atom engineering may unlock versatile platforms for high-performance electrochemical energy storage and efficient, earth-abundant catalysis. In the first part of the talk, I will trace how tailored graphene derivatives and organic architectures push the limits of batteries and supercapacitors. Examples include nitrogen-superdoped graphene with diamond-like interlayer bonds that reaches benchmark volumetric energies;1 graphene acid whose dense carboxylation raises its lithium-ion capacity beyond high quality single layer graphene;2 and self-assembled organic nanowire Li-ion anodes that store up to 1900 mAh g-1.3 Such graphene derivatives also enable direct up-cycling of spent sorbents for water purification into electrodes for energy storage, mitigating costs and wastes through circular design and sustainable resource management principles.4

The second part highlights catalytic technologies that exploit materials of similar design, which are key to decreasing the energy and environmental footprint of the chemicals industry. An aminoacid-anchored graphene acid organocatalyst outperforms homogeneous acids for solvent-free valorization of waste organics and for biofuel production.5 Embedding earth abundant transition metal atoms in such graphene derivatives affords redox-switchable mixed-valence catalysts that efficiently drive aerobic oxidative transformations of lower-value molecules to key chemicals for the pharmaceutical and polymer industry.6 Together, these studies demonstrate how molecularly functionalized materials and metal-carbon seamless architectures can deliver advances in catalysis for low energy organic transformations and electrochemical energy storage technologies.

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