Bottlebrush Polymers, Networks, Gels, and Devices

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A bottlebrush polymer consists of a long linear backbone densely grafted with many relatively short side chains. Unlike classical linear polymers, the bottlebrush architecture enables mechanical, biophysical, and biochemical properties to be encoded independently, making bottlebrush polymers a versatile platform for soft (bio)materials design and innovation. In this talk, I will describe my lab's recent efforts to understand and apply bottlebrush polymers. I will begin with a theoretical framework for their molecular structure. Corroborated by experiments, we discover that, in some cases, the bottlebrush backbone can fold to store length despite the strong steric repulsion among highly overlapping side chains, a finding that challenges the prevailing view [1]. I will show that using these "foldable" bottlebrush polymers as network strands offers a universal strategy to decouple intrinsic stiffness-extensibility tradeoff in unentangled single-network elastomers, the fundamental component of all kinds of polymer networks [2]. I will then highlight a few applications of bottlebrush polymers and networks, including therapeutic delivery [3], modular cell-instructive biomaterials, advanced (bio)manufacturing [4], and high-performance solid-state polymer electrolytes. I will also discuss open questions unique to bottlebrush polymers, including glass transition, molecular dynamics, entanglements, and machine learning–accelerated polymeric materials discovery.

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[2] B. Huang, S. Nian, L.-H. Cai. *Science Advances* (2024) **10**, eadq3080.
[3] Z.-J. He, B. Huang, L.-H. Cai. *ACS Nano* (2024) **18** 17586-17599.
[4] B. Huang, M. Kim, P. Zhang, E. Oduro, D.A. Rau, L.-H. Cai. *Advanced Materials* (2026) **38** e1280629.