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THE NEXUS OF MATERIALS, ENERGY, AND CARBON DIOXIDE - AND HOW NEW CARBON MATERIALS CAN TRANSFORM IT

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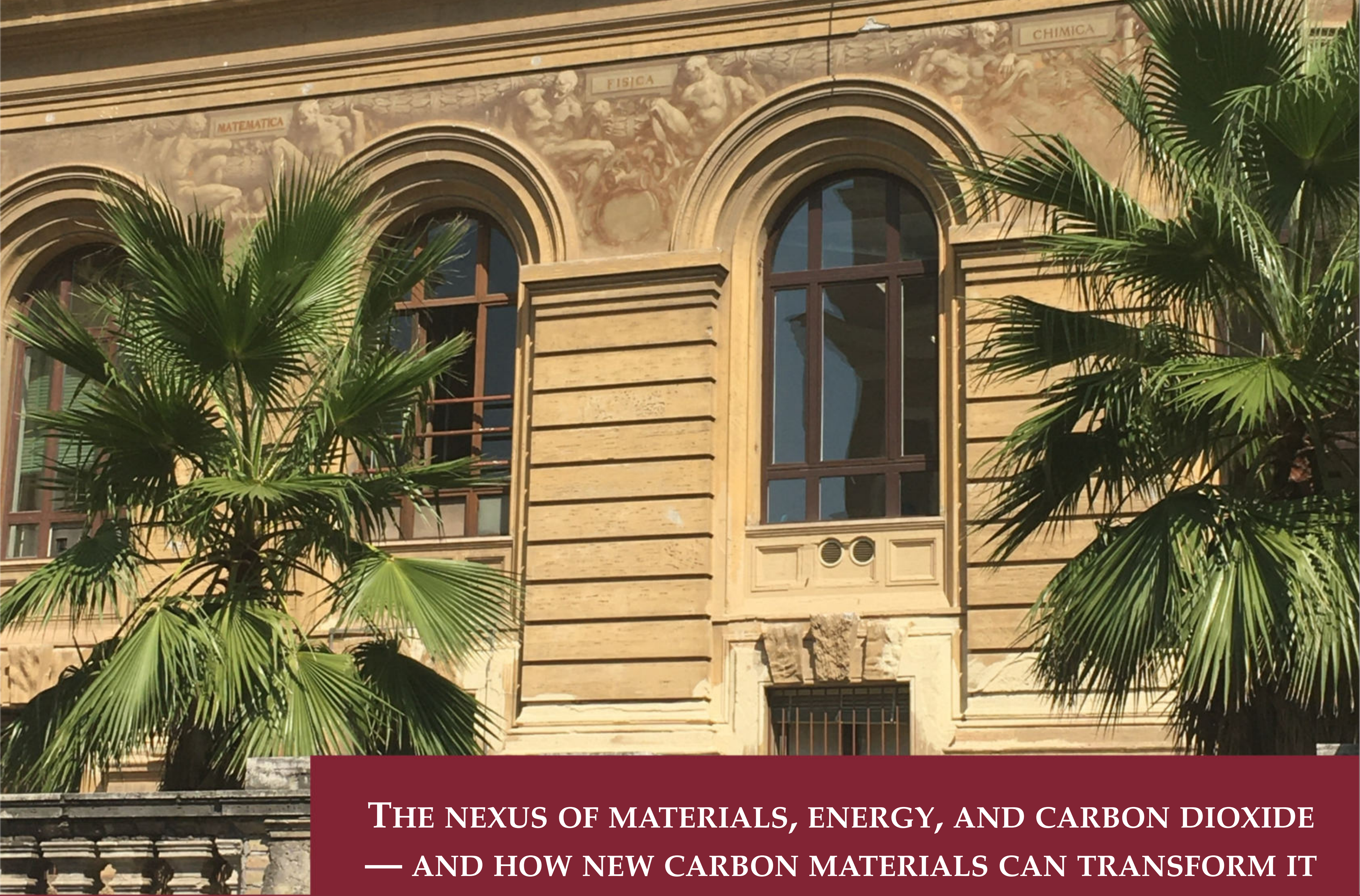

The nexus of materials, energy, and carbon dioxide — and how new carbon materials can transform it

Achieving a sustainable economy requires a transition in materials. Continued use of metals poses particular problems, because they are mined as oxides, often at low concentration and in fragile ecological areas; their conversion requires considerable energy and generates CO2 emissions. Metals are inefficient because of their high density; moreover, their supply chains are geopolitically vulnerable. Can we develop more sustainable, secure materials whose production requires less energy, does not generate CO2, and perform the same functions as metals and other CO2-intensive materials?

In this lecture, I will explain that small-diameter, single-walled and few-walled carbon nanotubes (CNTs) are the likely solution. These CNTs are essentially conducting (fully conjugated) polymers with very high degrees of chemical and mechanical stability; they can be synthesized from hydrocarbons, with co-production of hydrogen. These CNTs are effectively precursors that can be solution-processed into macroscale CNT materials whose properties overlap industrial metals (copper, aluminum, steel). To displace CO2-intensive materials at large scale, CNT materials must be made and processed efficiently—much like polymers had to be synthesized and processed inexpensively to replace natural materials and ceramics. Sounds like a job for chemical engineers?

Two classical branches of Chemical Engineering have been crucial for advancing this new field. Transport phenomena and thermodynamics have had a key role in understanding the solution behavior of CNTs and developing its processing. I will discuss how individual CNTs in liquids behave as stiff Brownian filaments, with diameter-dependent persistence length. As their concentration increase, they self-assemble into nematic liquid crystals and can be spun into continuous fibers, much like liquid crystalline polymers. On the synthesis side, catalysis and reaction chemistry were the initial focus of the field; reaction engineering has been gaining an increasingly important role. I will explain how continuous-flow CNT synthesis requires balancing and timing in-situ catalyst formation and hydrocarbon decomposition to achieve reaction high-throughput synthesis of high quality CNTs. Via a combination of in-situ measurements and multiscale modeling, CNT reactors are being progressively rationalized.

Interesting questions now arise at the interface of rheology and reaction engineering: CNTs form aerogels during the growth (polymerization-like) process. These aerogels are essentially suspensions of stiff, growing rods in a high-temperature gas. Understanding the formation and properties of these aerogels (a gas rheology problem?) is likely to be critical to achieving the necessary efficiencies in the synthesis processes.

The prize for solving these problems? A future where we can make materials sustainably from various carbon sources and use them to decarbonize industry, revitalize our manufacturing, electrify our energy systems, and rebuild our infrastructures.

Speaker Bio

Matteo Pasquali is the A. J. Hartsook Professor of Chemical & Biomolecular Engineering, Chemistry, and Materials Science & NanoEngineering at Rice University, where he also serves as Director of the Carbon Hub — the world's first institute devoted to developing and deploying the co-production of scalable carbon materials and clean hydrogen.

Since joining Rice University in 2000, Pasquali has served as Chair of the Department of Chemistry, Master of Lovett College, Senator at Rice University, Chief Scientific Advisor at Shell, and expert advisor to the board of Saudi Aramco. He is also Director of two startups he co-founded: DexMat and NanoLinea.

Pasquali is an elected Fellow of the American Association for the Advancement of Science, the American Physical Society, and the Society of Rheology. His awards include the AIChE Braskem Award for Excellence in Materials Engineering and Science, the NSF CAREER Award, the Goradia Innovation Grand Prize, the Herschel Rich Invention Award, the Schlack Prize for Man-Made Fibers, the Rice Presidential Mentoring Award, and the Kavli Exploration Award in Nanoscience for Sustainability.

Pasquali has advised over 100 graduate students and postdocs, co-authored over 250 scientific articles and 35+ patents (cited 24,000+ times). He holds a PhD from the University of Minnesota and an MS from the University of Bologna, both in Chemical Engineering.