Nature-Inspired Chemical Engineering: a NICE Approach to Grand Challenges in Sustainability

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Tackling Grand Challenges, framed by the UN Sustainable Development Goals (SDGs), requires step-changes through transformative approaches and interdisciplinary thinking, beyond incremental variations on traditional designs. Nature is replete with well-integrated, "intensified" systems, optimized over the eons, to satisfy stringent constraints for survival by scalable processes with emergent properties. We propose to take nature as a source of inspiration, leveraging fundamental mechanisms underpinning desirable properties (like scalability, resilience or efficiency) and applying these to engineering designs, including suitable adaptations to satisfy the different contexts of technology and nature. We call this Nature-Inspired Chemical Engineering (NICE), and the design and innovation methodology to practice it more broadly: Nature-Inspired Solutions (NIS).

The NIS methodology is thematic, structured around ubiquitous physical mechanisms in nature, such as: (1) hierarchical transport networks; (2) force balancing; (3) dynamic self-organization; and (4) ecosystems, control and modularity. It is also systematic, recognizing a suitable concept (e.g., fractal scaling within a certain range), then applying it to a design (e.g., a uniform, scalable fluid distributor) that supports implementation within an applied context (e.g., gas-solid fluidization). This systematic methodology makes NICE versatile: validated principles can be applied to new problems (e.g., from fluidization to fuel cells).

I will give NICE examples of the intensification of catalytic processes, membrane separations, and functional materials for space technology and biomedical applications. Many developments are underpinned by computation-assisted optimization. Molecular simulations, mesoscopic modeling, and non-equilibrium thermodynamics are key ingredients that require further fundamental development, complemented by machine learning and data-driven approaches.

References:

[1] M.-O. Coppens, 2012, A nature-inspired approach to reactor and catalysis engineering. *Curr. Op. Chem. Eng.* 1, 281-289.

[2] M.-O. Coppens and G. Ye, 2018, Nature inspired optimization of transport in porous media. In *Diffusive Spreading in Nature, Technology and Society* (A. Bunde, J. Caro, J. Kärger and G. Vogl, ed.), Springer.

[3] P. Trogadas, J.I.S. Cho, T.P. Neville, J. Marquis, B. Wu, D.J.L. Brett and M.-O. Coppens, 2018, A lung-inspired approach to scalable and robust fuel cell design. *Energy & Env. Sci.* 11, 136.

[4] M.-O. Coppens, T. Weissenberger, Q. Zhang and G. Ye, 2021, Nature-inspired, computer-assisted optimization of hierarchically structured zeolites. *Adv. Mat. Int.* DOI: 10.1002/admi.202001409

[5] M.-O. Coppens, 2021, Nature-inspired chemical engineering for process intensification. *Ann. Rev. Chem. Biomolec. Eng.* Submitted.