Beyond Steady-State: from Unconventional Operations to Unconventional Reactors

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Highlights

- Flexible synthesis loops reduce H_2 storage needs and lower the levelized product cost.
- Unconventional operations are the stepping stone toward unconventional reactor adoption.
- Electrification enables fast thermal cycling, unlocking dynamic catalysis beyond static limits.
- Energy-independent production at predictable cost reduces geopolitical and financial risk.

1. Abstract

The chemical industry is undergoing a fundamental shift driven by the rapid growth of variable renewable energy sources. Conventional catalytic chemical processes, designed around steady-state operation, are increasingly challenged by the intermittent nature of solar and wind power. This contribution presents Casale's perspective on how unconventional operations in catalysis — and ultimately unconventional catalytic reactors — represent the most effective response to this challenge.

We first examine the techno-economics of flexible ammonia and methanol synthesis, demonstrating that adapting the synthesis loop to follow renewable energy availability — rather than buffering variability through expensive upstream storage — reduces both capital expenditure and the levelized cost of the product. In the context of rising geopolitical risk and energy price volatility, energy-independent production at a stable, predictable cost offers a compelling investment case.

We then address process electrification as the enabling technology for catalytic dynamic operation. Electrification — e.g. through Joule heating, induction, microwave, and plasma — allows materials to heat and cool at rates unachievable with conventional thermal systems, enabling the catalyst to operate in a periodically forced regime. Under the right forcing conditions, the time-averaged catalytic rate can exceed the maximum achievable under any fixed static condition: a phenomenon known as dynamic catalysis. Ongoing R&D projects at Casale are exploring electrified monolith reactors, microwave-assisted catalysis, non-thermal plasma for CO_2 valorisation, and microwave-plasma torch processes for syngas generation.

Keywords

flexible chemical synthesis; dynamic operations in catalysis; process electrification; unconventional catalytic reactors