SCALABLE PRODUCTION OF Fe-N-C ELECTROCATALYST VIA TEMPLATE-ASSISTED MECHANOSYNTHESIS LEADING TO SUPERIOR ENERGY EFFICIENCY AND SUSTAINABILITY

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Efficient and sustainable synthesis of high-performing metal/nitrogen-doped carbon (M-N-C) catalysts for oxygen reduction and evolution reactions (ORR/OER) is crucial for the global transition to green energy technologies such as metal-air batteries and fuel cells. This research presents a solid-phase template-assisted mechanosynthesis method for Fe-N-C catalysts using affordable and sustainable $FeCl_3$, 2,4,6-tri(2-pyridyl)-1,3,5-triazine (TPTZ), and NaCl. The NaCl-templated Fe-TPTZ metal-organic material is produced using a simple liquid-assisted grinding/compression process. The Fe-TPTZ template provides stability, making the subsequent pyrolysis rapid and energy-efficient. Among the synthesised materials, 3D-FeNC-LAG demonstrates excellent performance in ORR ($E_{1/2}$ = 0.85 V, E_{onset} = 1.00 V), OER ($E_{j=10}$ = 1.73 V), zinc-air battery, and fuel cell tests. The Multi-Layer Stream Mapping framework shows that the synthesis process of 3D-FeNC-LAG achieves 90% overall process efficiency and 97.67% cost efficiency. The 3D-FeNC-LAG protocol requires only half the processing time (5.6h vs. 11+h) and one-third less energy (4.3 kWh vs. 14.7+ kWh) compared to the most advanced methods, making it superior.

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