Chapter 7
Computational Intelligence (CI) in the Sustainable Manufacturing of Emerging Materials for Energy Storage and Environmental Applications

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ABSTRACT

The demand for sustainable energy storage has driven advancements in material science, where Computational Intelligence (CI) is emerging as a key tool. CI techniques like machine learning and neural networks optimize complex processes, enhancing material properties and manufacturing efficiency. In energy storage, CI accelerates the discovery of materials for advanced batteries, supercapacitors, and hydrogen storage, improving energy density, cycle life, and safety. CI also aids environmental applications, such as water purification and carbon capture, by enhancing material performance. Despite challenges like data availability and computational resources, CI's integration into manufacturing promises a more sustainable future.

1. INTRODUCTION

1.1 Overview of Computational Intelligence (CI)

Computational Intelligence (CI) is a multidisciplinary field that encompasses techniques like neural networks, fuzzy systems, and evolutionary algorithms, which mimic natural processes and human reasoning to solve complex problems. Unlike traditional AI, CI relies on adaptive mechanisms to handle uncertainty, imprecision, and noise in real-world data. CI is particularly effective in areas where con-

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ventional models struggle, such as pattern recognition, optimization, and decision-making, making it crucial for advancing technologies in fields like energy storage, healthcare, and autonomous systems.

1.1.1 Definition and Key Techniques

The rapid advancement in technology and the increasing demand for high-performance materials have driven the need for innovative solutions in manufacturing. Computational Intelligence (CI) has emerged as a powerful tool, offering a transformative approach to solving complex problems in material science and manufacturing processes. CI encompasses a wide range of methodologies, including Machine Learning (ML), Artificial Neural Networks (ANNs), Genetic Algorithms (GAs), and Data-Driven Modeling. These techniques enable researchers and engineers to simulate, predict, and optimize previously challenging processes using traditional methods, (Bezdek & Pal, 1992).

Computational Intelligence (CI), often referred to as Soft Computing, represents an advanced framework for information processing, aimed at replicating and enhancing human cognitive processes such as perception, comprehension, learning, recognition, and reasoning. CI encompasses a broad array of computational paradigms that are biologically and linguistically inspired, facilitating the development of systems capable of flexible and adaptive information processing.

Traditionally, CI is founded on three core paradigms:

a. Neural Networks (NNs): Inspired by the structure and functionality of the human brain, artificial neural networks are massively parallel distributed systems. They possess the ability to learn and generalize from examples, making them powerful tools for tasks such as pattern recognition, classification, and prediction.
b. Fuzzy Systems (FS): Drawing from the imprecision inherent in human language, fuzzy systems address problems involving uncertainty and vagueness. They generalize classical logic to perform approximate reasoning, enabling decision-making in ambiguous environments.